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79th SMPTE Convention • Apr. 29–May 4, 1956 • Hotel Statler, New York

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JOURNAL of the
SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

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SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

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Executive Secretary: BOYCE NEMEC

Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879, and published monthly.

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Printed by Mack Printing Company, Easton, Pa.

Journal of the Society of Motion Picture and Television Engineers

VOLUME 64 • NUMBER 11 • NOVEMBER 1955

Image Gradation, Graininess and Sharpness in Television and Motion-Picture Systems

Part IV, A & B: Image Analysis in Photographic and Television Systems (Definition and Sharpness)

By OTTO H. SCHADE

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SYMBOLS

a_p Amplitude coefficient
A Area
c A constant
f Frequency; $f(x,y)$ a function of x and y
f: f:-number of a lens
$F(x)$ Line-transmittance function
F' Focal distance
$g(N)$ Fourier transform of a function $f(x)$
G Transfer factor
h Horizontal component (angle $\rho = 0°$)
I Intensity, I_0 of object, I' of primary image, I_2 of image
k,K Constants
l length
N Line-number, the index ρ specifies the direction of the sine-wave spectrum
N_δ Line-number at which the half-wave length equals aperture diameter
n_r Raster constant, number of line traces in vertical frame dimension
N_e Equivalent passband, $N_{e(T)}$ of television system, the indices h, v, or ρ specify the direction of the sine-wave spectrum
$N.A.$ Numerical aperture of a lens
$Q(x)$ Edge transition function
r Radius
$r_{\mathfrak{f}}$ Sine-wave response factor of a two-dimensional aperture; first index (a) (b), (K) specifies element, second index h, v, ρ specifies direction
$r_{\mathfrak{f}(a)}$ Sine-wave response factor of aperture system including camera tube and all apertures preceding raster process
$r_{\mathfrak{f}(b)}$ Sine-wave response factor of aperture system including kinescope and all apertures following raster process
$r_{\mathfrak{f}(a)h}$ Sine-wave response factor of system in the horizontal direction ($\rho = 0°$)
$r_{\Delta(\hat{\psi})}$ Square-wave amplitude response factor, Eq. (106)
$r_{\Delta(\hat{\psi})}$ Square-wave flux response factor, Eq. (107)
$[R]$ Signal-to-deviation ratio
s_e Effective length of an aperture
t Time
T Line-transmittance or impulse transmittance, Eq. (96).
u Angle between object point and lens axis, Fig. 137
U Electric vector amplitude
v Vertical component
V Volume of aperture or point-image
x,y Coordinates, x in the direction of scanning
δ Characteristic aperture diameter
ϵ Base of natural logarithm
ξ,η Coordinates of point-image or aperture
ρ Angle between aperture coordinate ξ and scanning direction x
τ Transmittance of aperture, relative intensity value of point-image
θ Phase angle
θ' Angle, see Fig. 137
ψ Flux
λ Wave length of light
μ Angle, see Fig. 130
$\omega = 2\pi f$

Presented by Otto H. Schade, Tube Div., Radio Corp. of America, Harrison, N.J., in part on October 15, 1951, and on April 28, 1953, at the Society's Conventions at Hollywood and at Los Angeles, Calif., and as a paper presented on November 10, 1953, before the Rochester, N.Y., Section of the Optical Society of America.

Note: Part I of this paper, "Image structure and transfer characteristics," was published in this *Journal* in February 1951, pp. 137–171; Part II, "The grain structure of motion picture images—an analysis of deviations and fluctuations of the sample number," in March 1952, pp. 181–222; and Part III, "The grain structure of television images," in August 1953, pp. 97–164.

(This paper was received on May 24, 1955.)

SUMMARY OF PART IV

The theory of image formation and analysis is formulated in Section A as an "aperture theory" applied to optical and electrical image-forming systems. It is shown that the properties and combination of "apertures" (point-images) can be described in the space domain by transmittance functions and in the frequency domain by their Fourier spectra (sine-wave response). The mathematical formulation demonstrates that the basic operation of image formation and analysis is a successive integration of the products of two functions, letting one function "scan" the other function, mathematically termed "convolution." The equivalent passband N_e of an aperture or system emerges again as a significant and convenient parameter for specifying their characteristics by a single number.

The application of aperture theory to the evaluation of properties of image-forming devices such as lenses, photographic systems and television systems is treated in Section B, which contains a new approach to lens evaluation and general specifications for the design of television systems.

Subsequent sections of Part IV, which are to be published at a later date, will discuss practical instruments for measuring the sine-wave spectra of the elements in photographic and television systems, and the sine-wave spectra of the visual process. Part IV will conclude with the description of a system for evaluating and comparing the sharpness of optical and television images, based on their equivalent passbands.

INTRODUCTION

An ideal imaging system is expected to focus radiation from any object point again into a mathematical point. This performance cannot be realized with a system of finite aperture because of diffraction at its boundaries. The actual *point-image* has physical dimensions, and its shape and intensity distribution determine definition and resolution in the image. It is immaterial whether the point images in a frame area are formed simultaneously or in sequence (as in television), provided they are formed within a time suitable for the particular purpose. The accuracy of reproduction can be specified mathematically by a description of the "point image" in the space domain or frequency domain or by its effect on known object functions. Analytic treatments of two-dimensional point images and intensity functions by Fourier methods go back to early studies of interference and diffraction in optical instruments and may be found in textbooks on optics (for example, Ref. 1). Although not generally applied to evaluate and specify the performance of two-dimensional imaging systems such as the photographic process, Fourier methods have been used extensively in communication theory to analyze and specify the performance of electrical circuits and systems. The transmission of image information over a single-channel television system requires translation of two-dimensional intensity functions $I = f(x,y)$ into one-dimensional electrical signals $I = f(t)$, which is accomplished by a periodic process of scanning. The mathematical relations between image functions and television signals, and particularly their frequency spectra in the electrical channel have, therefore, received early attention.[2] A more complete analysis of practical imaging systems containing a large number of elements in cascade must often depart from idealizing assumptions and rely on data obtained by measurement of actual system components. In the course of an extended study, it has been found advantageous to break up general functions into three parts which can be treated and combined independently.

(1) *The relations of mean intensities* between corresponding aggregates of point images and point sources in the object are described by *transfer characteristics*. Depending on the nature of the system element, the quantities related by its static or dynamic transfer characteristics are intensities of optical or electrical "signals" which may be measured and combined as discussed in Part I of this paper. The information given by a transfer characteristic is incomplete because it relates intensities of large areas only, and defines the constants of the image-intensity function but not its fine structure.

(2) When the test areas are reduced to the order of a point image, it is observed in all practical imaging systems that changes in test position result in intensity readings which deviate randomly from each other. A large number of "sample" readings must then be taken to obtain a mean value which agrees with the reading obtained from a large test area. Random deviations from the average disturb the uniformity of "signal" levels, and limit detection of intensity differences to the order of the deviations themselves. *The signal-to-deviation ratio* $[R]$ (electrically: signal-to-noise ratio) is a second basic characteristic needed for specifying image quality. The analyses of motion-picture and television grain structures in Parts II and III of this paper have shown that the signal-to-deviation ratio $[R]$ of an image is a function of signal intensity, and that $[R]$ is determined with a test area or sampling aperture equivalent to the point image of the entire process following the source of deviations. It was found expedient to determine this equivalent aperture from its properties in the "frequency domain," i.e. from its sine-wave "spectra."

(3) *The accuracy in the reproduction of detail* by an imaging system can be specified in the "space domain" by the intensity function of its point image, line-image, or edge transition, or it can be specified in the "frequency domain" by its Fourier transforms: the sine-wave response and phase-characteristics. The characteristics of the point image are determined in principle by physical or electrical apertures (wave filters) in combination with elements directing or focusing the aperture flux to form an image. The theory of evaluating and combining point images or their sine-wave spectra has therefore been termed aperture theory. The direct measurement of intensity distributions of optical or electrical point images requires high precision and has proven to be unreliable when simple, or when otherwise, complicated and time consuming. An exact determination of the spatial characteristics of the point image of a multistage imaging system from its individual point images is still more laborious, requiring progressive integration, because every point in the point image of a preceding stage must be replaced by the point image of the succeeding stage. Because of the complexity of practical point images, it is usually much more convenient to operate with their Fourier transforms (sine-wave response and phase characteristics) which can be measured and combined easily. The dimensions of corresponding "apertures" can be obtained from inverse transforms and by graphic methods. *The sine-wave spectrum* can be regarded as the third basic characteristic determining image quality, because any form of intensity variation can be expressed by Fourier series of sine-wave components with particular amplitude and phase relations. To avoid waveform distortion, the sine-wave response is determined with small "signals" for which all transfer characteristics are linear. Large signals in nonlinear systems can be analyzed as customary for electron-tube amplifiers.

A study of the characteristics of optical and electrical elements in practical imaging systems extending over many years has led to preferred methods of analysis, supported by a parallel development of instruments[3,4] for accurate measurement of sine-wave response characteristics. In mathematical terms such instruments perform the function of "computing" the transforms of point images used in practical systems.

A temporary difficulty encountered in the measurement of the sine-wave response of optical or photoelectric devices, for example, has been the lack of sine-wave test objects. Because of the general use of "square-wave" test charts (normal line patterns) it appeared desirable to

develop methods for interpreting square-wave response characteristics.[5] The Fourier relations between square-wave and sine-wave response factors of practical two-dimensional point images are in many cases fairly simple, permitting a conversion. The direct measurement of sine-wave response factors, however, is advisable, particularly when one is dealing with raster processes, limited frequency channels, and eccentric point images (coma) causing phase shifts. The response to square waves, single edges or other complex wave-forms can be computed accurately from the sine-wave amplitude and phase response and the transfer characteristics of the system.

The introduction of an equivalent normalized point image (sampling "aperture") and frequency spectrum, specified by a single number (the equivalent passband N_e), resulted in a great simplification of many problems in the analysis of grain structures. These equivalents are equally useful and significant in the evaluation of image definition and sharpness and lead to a new system of rating image-forming devices or systems. A direct connection between objective characteristics and subjective impressions can be established by the inclusion of the objective characteristics of the process of vision in the evaluation. For this purpose a useful analog of the visual system, in agreement with fundamental principles, has been determined from subjective data.

This paper presents the first Sections A and B of Part IV which outline the theory of image formation by two-dimensional "apertures," their description in the space and frequency domains, as well as a discussion of fundamental properties of image-forming systems including the "perfect" lens and the "perfect" television system. Methods of measuring the actual performance of lenses, microscopes, television system components and the eye will be treated in subsequent sections of Part IV, which will demonstrate the evaluation of definition and sharpness in complete imaging systems such as motion pictures and television.

A. THEORY OF IMAGE ANALYSIS (APERTURE THEORY)

1. Intensity of a Point in the Image Plane

The intensity I_0 in an object plane is a function of the object frame coordinates

$$I_0 = f(x_0,y_0)$$

An imaging process causes in general a change of coordinate lengths, a change of the intensity scale, and an expansion of all point sources into point images. The first two effects on the image are considered separately by the assumption that the point image is infinitesimal. The hypothetical image so obtained will be termed "primary image," and has the intensity distribution

$$I' = GI_0 = f(x_1,y_1) \qquad (91)$$

where G is the transfer factor of the process, x_1 and y_1 are the coordinates of the primary image which has been changed by the magnification factor $l_1/l_0 \equiv x_1/x_0,y_1/y_0$. The type of imaging system is arbitrary.

The effect of a real point image can now be discussed in relative units with direct reference to the coordinates and

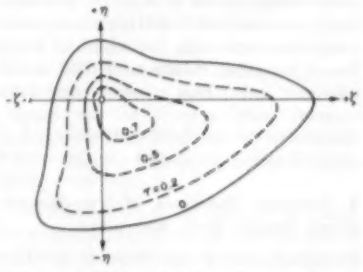


Fig. 110a. Topographic representation of point-image or aperture-transmittance.

intensity (I') of the primary image. The point image is treated as an *aperture* with coordinates ζ and η placed through a reference axis O as illustrated by Fig. 110a. The relative intensity of the point image is specified by the *aperture transmittance* τ indicated topographically by contour lines. The reference axis O indicates the location (coordinates (x_1,y_1) in the primary image) of the point source which causes this point image. The reference axis is usually placed at $\tau = \tau_{max}$. A precise location is not essential because an error in position causes merely a corresponding and insignificant displacement of the entire image frame.

The total energy or intensity $I_{s(P)}$ at a point P of the image is *the sum of intensity contributions* from all point sources for which P lies inside the transmittance range of their point image as indicated in Fig. 110b. Summation of energies is indicated because the phase relation of electric field-vectors in the radiant energy from different object or image points are random (incoherent) in all stages of a photographic or television process. To simplify notation, let P be the origin of the coordinate system (x_1,y_1). The contribution from a point source O_n is the product of its primary intensity I'_n and its point-image intensity or aperture-transmittance τ at point P. Because the coordinates of the points O with respect to P and of P with respect to O are always equal and of opposite sign, the intensity I'_n and corresponding trans-

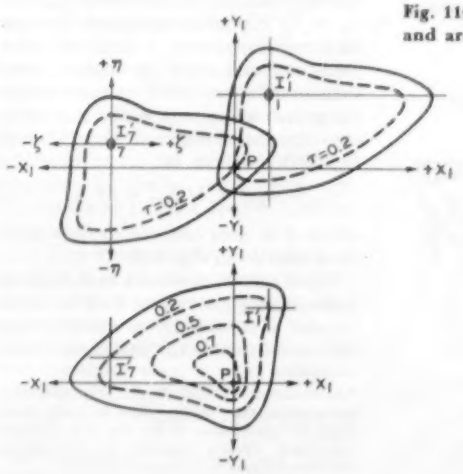


Fig. 110b. Intensity of an image point and area of correlation.

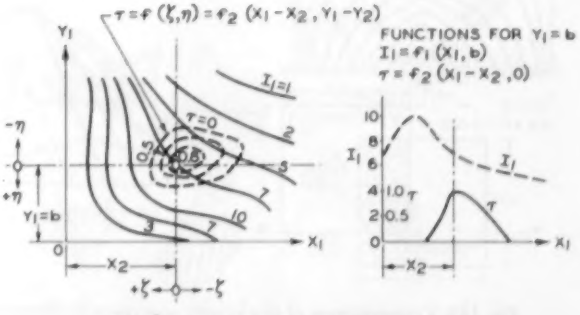


Fig. 111. Intensity function of an image.

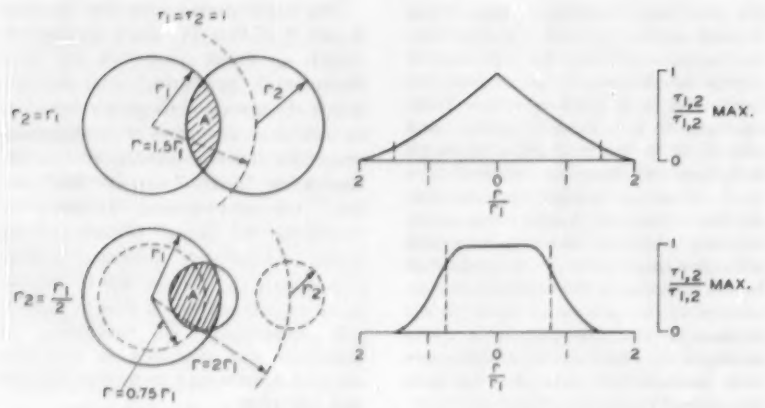


Fig. 112. Transmittance of two circular apertures (uniform transmittance) in cascade.

mittance τ can be coordinated for all products by letting points P and O coincide and rotating the point image and its coordinates 180° as shown in Fig. 110b. Corresponding intensity and transmittance values now coincide in location. The total intensity at point P, ($x_1 = 0$, $y_1 = 0$) is hence with Eq. (91):

$$I_{2(P)} = G \iint_{-\infty}^{\infty} f_1(x_1,y_1) f_2(x_1,y_1) dx_1 dy_1 \quad (92)$$

where $f_1(x_1,y_1) = I'$ is the intensity function of the primary image and $f_2(x_1,y_1) = f(-\xi, -\eta) = \tau$ is the transmittance function of the point image. The unit for τ is determined by assuming a uniform object intensity I_0 = constant, for which $G = I'/I_0$. Equation (92) reduces to $\iint_{-\infty}^{\infty} f(x_1,y_1) dx_1 dy_1 = 1$, which is the "volume" of the point image.

Numerical intensity values are hence determined with a point-image volume normalized to unity. Numerical transmittance values decrease, therefore, with increasing point image size. For many purposes, however, it will be found convenient to express the transmittance in relative units, letting τ_{max} equal unity.

It is evident from Fig. 110b that the area and degree of correlation of point sources contributing to the intensity of a single image point P is given precisely by the area and transmittance of one point image identical with that obtained from the object point *P but rotated 180°* on its reference axis. This rotation and sign reversal, with respect to the image, should not be confused with the normal image rotation by optical systems.

2. Intensity Functions of Two-Dimensional Images and Apertures

Intensity Function of an Extended Image: The image intensity function $I_2 = f(x_2,y_2)$ of an extended image containing the aperture effect can be derived from Eq. (92). The aperture function (f_2) must be modified so that it expresses the orientation (ρ) and shift of the aperture to all points (x_2,y_2) of the extended image:

$$\tau = f(-\xi, -\eta) = f_2[\rho, (x_1 - x_2), (y_1 - y_2)] \quad (93)$$

The orientation of the aperture with respect to the image coordinates is expressed by the angle ρ formed between the aperture coordinate ξ and the image coordinate x_1. The relations between the coordinate systems of primary image (x_1,y_1), aperture (ξ,η), and actual image (x_2,y_2), are illustrated in Fig. 111. Substitution of the above expression (93) into Eq. (92) furnishes the intensity I_2 of the extended image:

$$I_2 = f(x_2,y_2) = c \iint_{-\infty}^{\infty} f_1(x_1,y_1) f_2[\rho, (x_1 - x_2), (y_1 - y_2)] dx_1 dy_1 \quad (94)$$

where c is a constant. The variable point coordinates (x_2,y_2) are treated as constants during evaluation of the double integral for each image point. Progressive variation of x_2 or y_2 causes the aperture (function f_2) to "scan" the primary image (function f_1). *The mathematical process of one function scanning another function, as expressed by Eq. (94), is termed "faltung" or "convolution;"* the function (93) is a "scanning function."

The image-synthesis by convolution of object and aperture functions according to Eq. (94) is applicable to any object configuration. The extended use of this theorem is pointed out in the following sections.

Transmittance of Apertures in Cascade: The apertures of a multistage imaging process can be combined into one "system aperture" by cascading (convolution), i.e. by repeated application of Eq. (94).* In other words, the point-transmittance $\tau_{1,2} = f(x,y)$ for two aperture processes in cascade is computed by scanning the transmittance function τ_1 of one aperture (which is considered the object) with the transmittance function τ_2 of the second aperture. The result depends again on the relative orientation of the two aperture coordinate systems expressed by the angle ρ between their ξ-coordinates. Writing, therefore, $\tau_1 = f_1(\rho,\xi,\eta)$ and $\tau_2 = f_2[(\xi - x), (\eta - y)]$, one obtains an expression similar to Eq. (94):

$$\tau_{1,2} = f(\rho,x,y) = c \iint_{-\infty}^{\infty} f_1(\rho,\xi,\eta) f_2[(-\xi - x), (-\eta - y)] d\xi d\eta \quad (95)$$

The constant c is eliminated by computing the relative transmittance $\tau_{1,2}/\tau_{1,2\,max}$.

The cascaded transmittance of two *apertures with uniform transmittance* ($\tau_1 = \tau_2 = 1$) is readily calculated. In case of circular symmetry ρ drops out as a parameter and the transmittance function need be evaluated only for points along one radius: $\tau_{1,2} = f(r/r_1)$ as indicated by the examples in Fig. 112, and Eq. (95) simplifies to

$$\tau_{1,2}/\tau_{1,2\,max} = A/A_{max} = f(r/r_1) \quad (95a)$$

where A = area common to both apertures (shaded in Fig. 112).

When the two apertures have uniform transmittance but one or both are noncircular, it is necessary to consider their relative orientation (ρ), and compute the

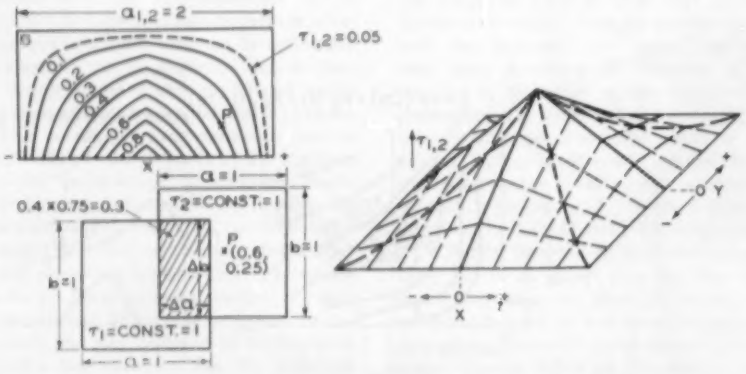


Fig. 113. Transmittance of two square apertures (uniform transmittance) in cascade.

* It is shown in Part B that the sine-wave spectrum of the "perfect" lens is easily computed by convolution of the lens stop aperture with itself. Certain examples in this section illustrate this process for later reference.

point-transmittance (Eq. (95a)) along a number of radii or parallel sections, because the system aperture is obviously noncircular. The topographic representations, Figs. 113 and 114, illustrate two typical cases.

When two apertures have nonuniform transmittance but circular symmetry the transmittance (Eq. 95) may be evaluated as a sum of partial integrals which can be computed with Eq. (95a). The apertures are subdivided into n and m circular discs respectively, having constant fractional transmittances.

The transmittance function, along a radius of each pair of sections n, m is:

$$\tau_{(n,m)} = A_{n,m}\tau_n\tau_m = f(r/r_1)_{n,m}$$

and their normalized sum is the relative transmittance along a radius of the system aperture.

This process of subdivision into component apertures is illustrated by the annular apertures in Fig. 115 where the blocked out centers can be treated as apertures with constant negative transmittance $\tau = -1$. The solid positive aperture (r_1) scanning (r_3) gives the positive partial transmittance curve 1,3. The two negative apertures (r_2) and (r_4) give the positive transmittance curve 2,4; and the negative apertures (r_2) and (r_4) scanning the positive apertures (r_3) and (r_1) respectively give the negative transmittance curve 1,4 + 2,3. The total transmittance (solid curve) is the sum of the partial transmittances which equals the result obtained by direct convolution.

It is apparent that the labor of computation becomes prohibitive in an analysis of practical processes containing a large number of elements. The method is, however, instructive inasmuch as it illustrates a number of basic facts:

(a) The exact diameter of the system aperture* is mathematically equal to the sum of the diameters of the component apertures (in the direction under consideration). The observed diameter in practical systems is not well defined for reasons stated below under *d*.

(b) The largest aperture in a system has a dominating influence on the form of the system aperture. A small aperture causes only minor changes in the transmittance function which become insignificant when the effective aperture diameter is smaller than one-third (approximately) of the largest aperture diameter.

(c) The transmittance of a system of apertures is in general nonuniform, even though the component apertures may have constant transmittance.

(d) The aperture of photographic systems containing three or more apertures of similar magnitude tends to be circular in shape and its transmittance tends to approach the form of an error curve $\tau = \epsilon^{-(r/r_0)^2}$. It must be emphasized that apertures caused by diffraction and apertures of electrical elements may alter this tendency as shown in Part III and discussed further in section B.

* The designations "aperture" and "point image" are interchangeable by definition.

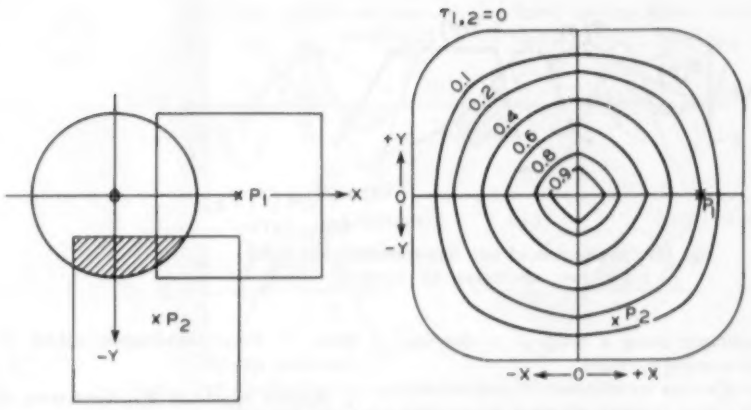


Fig. 114. Transmittance of circular and square aperture (uniform transmittance) in cascade.

3. Line-Images and Line-Transmittance Functions of Apertures (One-Dimensional Functions)

Because of the complexity of two-dimensional functions, optical test objects are given an intensity distribution $I_0 = f(x_0,0)$ or $I_0 = f(0,y_0)$ which is a function of one variable only. Such test objects are "line patterns." The image of a mathematical line object, is obtained by letting the point-image scan across a mathematical line object. The transmittance $T_{(\rho)}$ of the line-image, termed *line-transmittance* is expressed by

$$T_{(\rho)} = F(\rho,x) = \frac{1}{k}\int_{-\infty}^{\infty} \tau dy \quad (96)$$

where ρ is defined as the angle formed by the aperture coordinate ζ with the direction of scanning (x-coordinate) and k = maximum line-transmittance. When the aperture is pictured as a three-dimensional body, the integrals $T_{(\rho)}$ for $\rho = 0°$, for example, represent areas of aperture sections (slices) parallel to η, and integrals $T_{(\rho)}$ for $\rho = 90°$ are areas of sections parallel to ζ as illustrated in Fig. 116.

The line-transmittance functions $T_{(\rho)} = F(\rho,x)$ are *one-dimensional equivalents* which depend on the orientation (ρ) of the aperture coordinates relative to the line object. Because the line transmittance is the product of a base dimension and a corresponding *average transmittance*, it correctly specifies the relative intensity of a line image but not the actual trans-

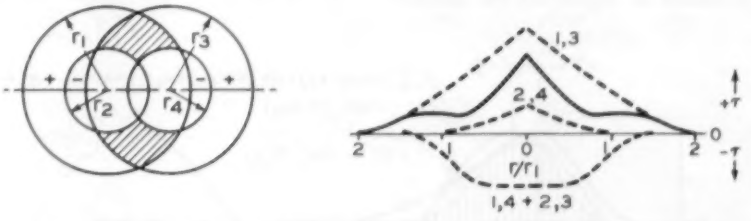


Fig. 115. Transmittance of two annular apertures (uniform transmittance) in cascade.

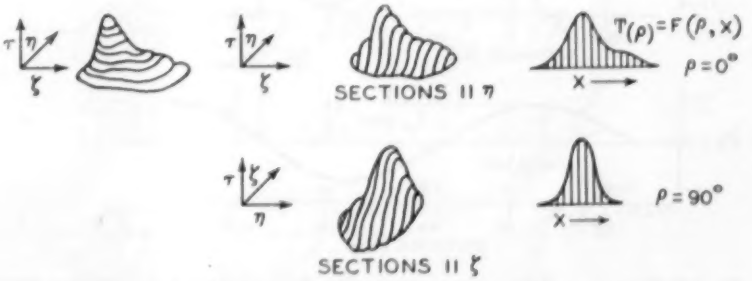


Fig. 116. Line-transmittance $T(\rho)$ of an aperture.

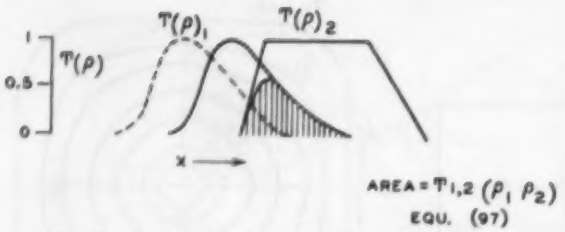


Fig. 117. Evaluation of one line-transmittance value for two apertures in cascade.

mittance along a diameter of the line-generating aperture.

The line transmittance of two apertures in cascade is again obtained by convolution, i.e. the line-transmittance function $T_{(\rho)1} = F_1(\rho_1,x)$ of the first aperture is scanned by the line-transmittance function $T_{(\rho)2} = F_2(\rho_2, x - x_2)$ of the second aperture as indicated in Fig. 117. The cascaded line transmittance at any one value x_2 is expressed in relative units by

$$T_{1,2(\rho_1,\rho_2)x_2} = F(\rho_1,\rho_2)x_2 = \frac{1}{k}\int_{-\infty}^{\infty} F_1(\rho_1, x)\, F_2[\rho_2, (x - x_2)]dx \quad (97)$$

where k = maximum line-transmittance value. When both line transmittances are symmetric about their reference axes, the maximum line transmittance $\tau_{1,2\ max}$ occurs obviously when the reference axes coincide, i.e. at $x_2 = 0$.

The line transmittance of apertures or aperture systems is usually determined only for two perpendicular line directions because practical apertures have often a circular or elliptical form. This fact is obtained by observation and is required as additional information when it is desired to reconstruct the aperture from its line-transmittance values or sine-wave spectra.

4. Fourier Spectrum Representation of Apertures

The intensity distribution of an optical line pattern can be expressed by a *one-dimensional periodic function* (Fourier series) containing an average term I_0 and one or a series of harmonic sine-wave terms termed a *line spectrum*. The image-intensity function, obtained by convolution with an aperture, has the same line spectrum, but differs from the object function in amplitude and phase of the terms. The differences, expressed by amplitude factors and phase angles, have values which are characteristic of the particular aperture. The sine-wave response factor $r_{\vec{g}}$ and phase angle θ of the aperture is a function of frequency, or line-number N. In a linear system (small signals) the sine-wave response factor is independent of the line spectrum of the object function, and can be determined from a series of object functions containing only one sine-wave term. *The continuous function $r_{\vec{g}}$, $\theta = g(N)$ obtained by convolution with sine-wave objects of constant amplitude and line numbers from $N = 0$ to ∞ is a normalized Fourier spectrum or transform of the aperture.* The "spectrum" $g(N)$ depends on the orientation of the aperture with respect to the line-pattern and is, in general, a function of the angle ρ formed between the aperture coordinate ζ and the scanning direction. The complete sine-wave spectrum representation of a two-dimensional aperture is hence expressed by $r_{\vec{g}},\theta = g(\rho,N)$. *The "spectra" of practical apertures can be measured with instruments performing the integrations discussed in the following analysis.*

The intensity of an optical sine-wave pattern (Part II, Fig. 40), uniform in y, is expressed by $I_0 = f(x_0, 0) = \bar{I}_0 + I_{0\ max} \cos(\omega x_0)$ where $\bar{I}_0$ = average intensity, $I_{0\ max}$ = amplitude of sinusoidal intensity with the angular frequency $\omega = 2\pi f$.

Because the (television) line-number N has been defined as the number of half-cycles in a unit length ($N = 2f$), the variational (frequency) term in the above equation can be written:

$$\tilde{I}_0 = f(x_0) = \tilde{I}_{0\ max} \cos(\pi N x_0) \quad (98)$$

The average term is omitted because it is specified separately by the transfer characteristic. Although the total intensity I_0 is always positive in optical patterns, the variational components have positive and negative intensities or flux values with respect to the average level $\bar{I}_0$ which is their zero reference axis.

The image intensity function $I_2 = f(x_2)$ is obtained as before by convolution (compare Eq. (97)) i.e. by scanning the primary object function $I_1 = f(x_1) = \cos(\pi N x_1)$ with the line-transmittance function $T_{(\rho)} = F(\rho, -x) = F(\rho, x_1 - x_2)$ of the aperture as illustrated by Fig. 118.

With this notation the sinusoidal component of the image intensity is

$$\tilde{I}_2 = f(x_2) = \frac{1}{A}\int_{-\infty}^{\infty} F[\rho, (x_1 - x_2)]\cos(\pi N x_1)dx_1 \quad (99a)$$

This function represents a pure sine wave

$$\tilde{I}_2 = \tilde{I}_{2\ max} \cos(\pi N x_2 + \theta) \quad (99b)$$

and will give the desired response factor $r_{\vec{g}(N)} = \tilde{I}_{2max}$ when normalized by letting A equal the volume of the point image (compare Eq. (92)) which equals the area under the line transmittance curve

$$A = \int_{-\infty}^{\infty} F(x_1)dx_1 \quad (99c)$$

When the line transmittance is an even function $F(-x_2) = F(x_2)$, i.e. symmetric with respect to the reference axis T_{max}, the response factor $r_{\vec{g}(N)} = \tilde{I}_{2max}$ is obtained when T_{max} coincides with the sine-wave amplitude. The phase angle is $\theta = 0$ and the response factor can be

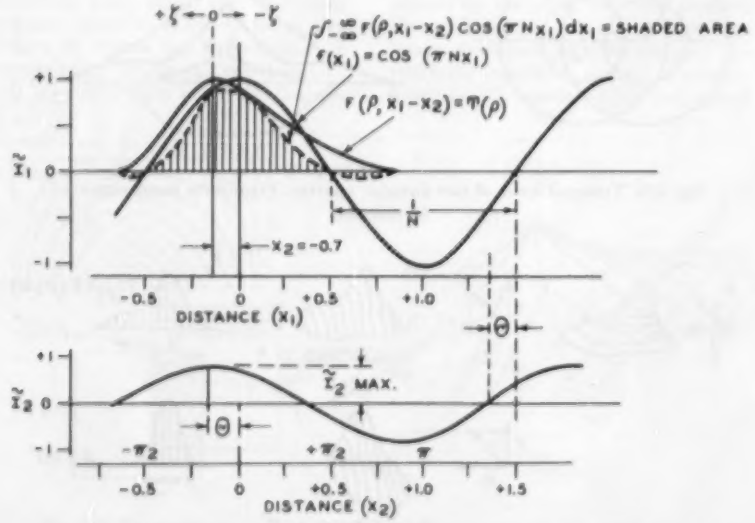


Fig. 118. Evaluation of sine-wave response (I_2) of an aperture by scanning a sine-wave function $f(x_1)$ with the line-transmittance $T(\rho)$ of the aperture.

calculated from a single aperture position:

$$r_{\phi(N)} = \frac{1}{A}\int_{-\infty}^{\infty} F(x_1)\cos(\pi N x_1)dx_1 \tag{100}$$

where

$$F(x_1) = T_{(x_1)}; \qquad A = \int_{-\infty}^{\infty} F(x_1)dx_1$$

In general, the response factor or maximum value of Eq. (99) can be determined from two aperture positions having a phase difference of $\pi/2$ with respect to the sine-wave object as shown in Fig. 119. The two positions furnish the well known coefficients

$$a_N = \frac{1}{A}\int_{-\infty}^{\infty} F(x_1)\cos(\pi N x_1)dx_1$$

and

$$b_N = \frac{1}{A}\int_{-\infty}^{\infty} F(x_1)\sin(\pi N x_1)dx_1 \tag{101}$$

and the response factor:

$$r_{\phi(N)} = (a_N^2 + b_N^2)^{\frac{1}{2}}; \qquad \theta = -\tan^{-1}(b_N/a_N)$$

The sine-wave response factor and phase angle are functions of line-number (N) and are termed a *Fourier spectrum*. A two-dimensional aperture has an infinity of spectra depending on the aperture orientation (ρ) with respect to the line pattern. The aperture is described in the "space domain" by the transmittance function $\tau = f(\zeta,\eta)$ or by an infinity of one-dimensional line-transmittance functions $T = F(\rho,x)$ depending on orientation. The Fourier spectrum representation

$$r_{\phi,\theta} = g(\rho,N) \tag{102}$$

is a description of aperture properties in the "frequency domain" which is as complete as its transmittance representation in the space domain. Stated mathematically, the spectrum representation $g(\rho,N)$ is the *transform* of the function $f(\zeta,\eta)$.

Apertures with circular symmetry ($\theta = 0$) have identical spectra for all values of ρ. The sine-wave spectra $r_\phi = g(N)$ of various symmetric apertures are shown in Part II, Figs. 41 to 46, and Part III, Figs. 94 to 97.

A number of fundamental relations of the space-domain and frequency domain representations are illustrated by Fig. 120. It is important to keep in mind that the transmittance (τ) is two-dimensional, while corresponding pairs of line-transmittance ($T_{(\rho)}$) and transform ($r_{\phi(\rho)}$) are one-dimensional functions, having eliminated one variable by integration permitted by the line-object. The functions $T_{(\rho)}$ and $r_{\phi(\rho)}$ are hence single axial cross sections of the "bodies" shown in Fig. 120. These line-transmittance- and transform bodies are generated by varying the direction of integration (ρ). A number of important relations may be pointed out:

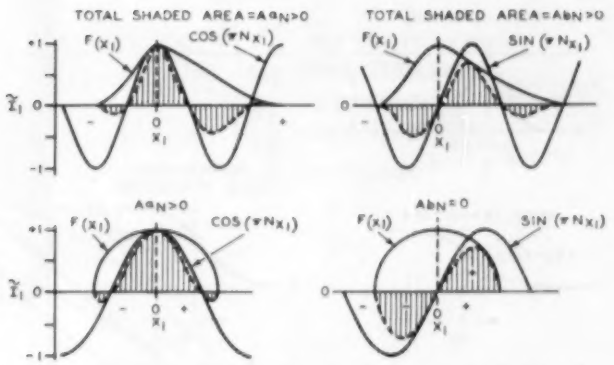


Fig. 119. Evaluation of cosine and sine-coefficients for an asymmetric aperture (top) and a symmetric aperture (bottom).

(a) Deformation or change of an aperture diameter by multiplication of one or both coordinates (ζ,η) by a scale factor a causes a reciprocal deformation of the transform body (in corresponding directions) by the factor $1/a$. (See elliptical aperture #5 Fig. 120.) In other words, when the aperture is increased, its spectrum shrinks.

(b) When all transmittance functions $\tau = f(\rho,x)$ are even, the transform body $g(\rho,N)$ and the aperture body are reversible; i.e. an aperture having the form of the transform body has a transform having the form of the aperture body; *the corresponding line-transmittance functions, however, are not alike* as illustrated by #1 and #2 and also #3 and #4 of Fig. 120. The one-dimensional relation, however, between a *line-transmittance (impulse function) and its single spectrum is reversible.* (A semicircular line-transmittance, for example, has a $(J_1(x))/x$ spectrum and a $(J_1(x))/x$ impulse has a semicircular spectrum.) Because of this reversibility, the line-transmittance of an aperture can be synthesized from its spectrum and the spectrum can be synthesized from its line-transmittance by the same method. Any even function $F(x)$ or $g(N)$, for example, can be expressed by a Fourier series of cosine waves (see Fig. 68 in Part III) which may be written in the form

$$f(x) = a_0 + \sum_{p=1}^{\infty} 2a_p \cos px, \qquad p = 1,2,3\ldots$$

where the symbols can be interchanged as follows:

For synthesis of line-transmittance $T = F(x)$

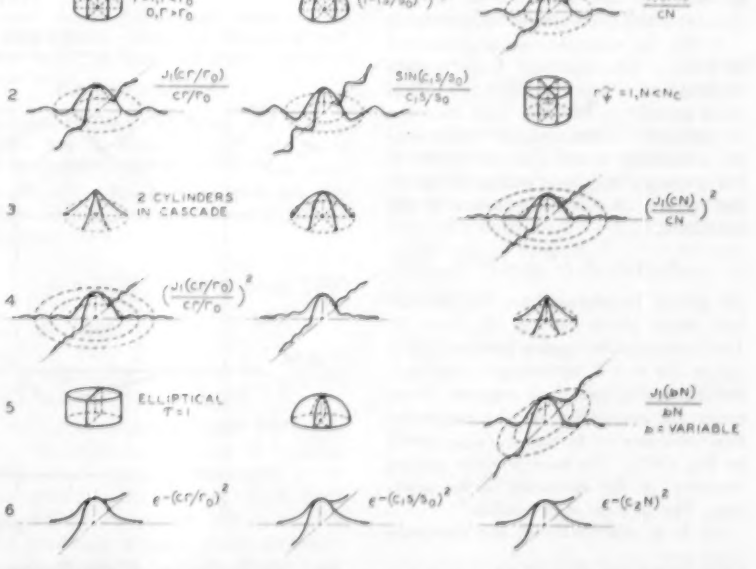


Fig. 120. Transmittance, line-transmittance, and spectrum of various apertures.

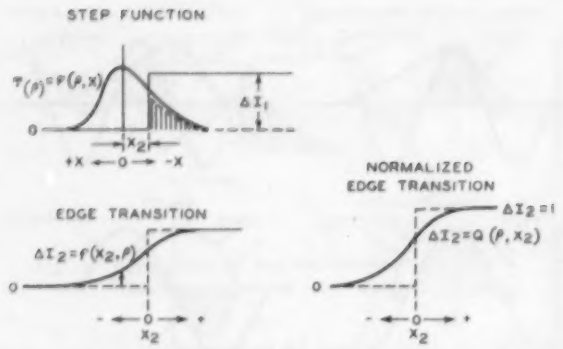


Fig. 121. Evaluation of edge transition ΔI_2 by scanning step function ΔI_1 with line-transmittance $T(\rho)$ of aperture.

from spectrum $r_{\not\delta} = g(N)$; $f(x) = F(x) = T$, $a_p = r_{\not\delta}$ at line number pN_1, ordinate length $x = 1/pN_1$ at $px = \pi$ of Fourier component.

For synthesis of spectrum $r_{\not\delta} = g(N)$ *from line-transmittance* $T = F(x)$; $f(x) = g(N) = r_{\not\delta}$, $a_p = T$ at distances px_1, ordinate length $N = 1/px_1$ at $px = \pi$ of Fourier component.

(c) *The spectrum of apertures in cascade* is the product of the individual aperture spectra. The mathematical operation in the space domain of cascading aperture- or line-transmittance functions by scanning (convolution) corresponds in the frequency domain to multiplication of their transforms. The aperture #3 in Fig. 120, for example, is obtained by cascading (convolution) of two #1 apertures. The spectrum #3 is hence the squared spectrum of the #1 aperture.

(d) When the transmittance function $\tau = f(x,y)$ of an aperture can be broken up into a *sum of transmittance functions*, its transforms are the vector sums of the partial transforms $g_n(\rho,N)$. The frequency spectrum of an aperture of circular symmetry and nonuniform transmittance $\tau = f(r)$, for example, can be evaluated as follows. The aperture body is subdivided into a "stack" of thin cylindrical slices parallel to its base. Each slice has a uniform transmittance (thickness) $\Delta\tau$, a diameter δ, and a volume $\Delta\tau\delta^2\pi/4$. For a normalized total volume of unity, the volume or flux contribution of the nth slice is

$$\psi_n/\psi_{\text{total}} = \delta_n^2\ \Delta\tau_n/\Sigma\delta^2\Delta t \quad (103)$$

All partial transforms have the normalized shape given by Fig. 42, Part II. Their line-number scales, however, have values $N\delta = 1/\delta$ according to the various diameters, and their response factor scales are multiplied by the respective flux contribution factors $\psi_n/\psi_{\text{total}}$ given by Eq. (103). The sum of these partial "spectra" is the spectrum of the aperture. The process is reversible.*

(e) It is observed that the spectrum products of a practical system containing three or more two-dimensional apertures of similar magnitude tend to approach the form of an error curve $r_{\not\delta}(N) = g(\rho,N) = \epsilon^{-(kN)^2}$ (Fig. 44, Part II). This tendency corresponds in the space domain to the tendency of the system aperture to become circular and have a transmittance and line-transmittance functions approaching error curves as illustrated by #6 Fig. 120. There are again exceptions when a large aperture or a small spectrum of unusual shape dominates the system as stated earlier, at the end of Sec. A, §2, of this Part.

5. Edge Transitions and Square-Wave Response

The intensity of a sharp transition (edge) is the sum of a steady intensity level I_1 and a step function ΔI_1. The corresponding image step function $\Delta I_2 = f(x_2,\rho)$ after an aperture process is ob-

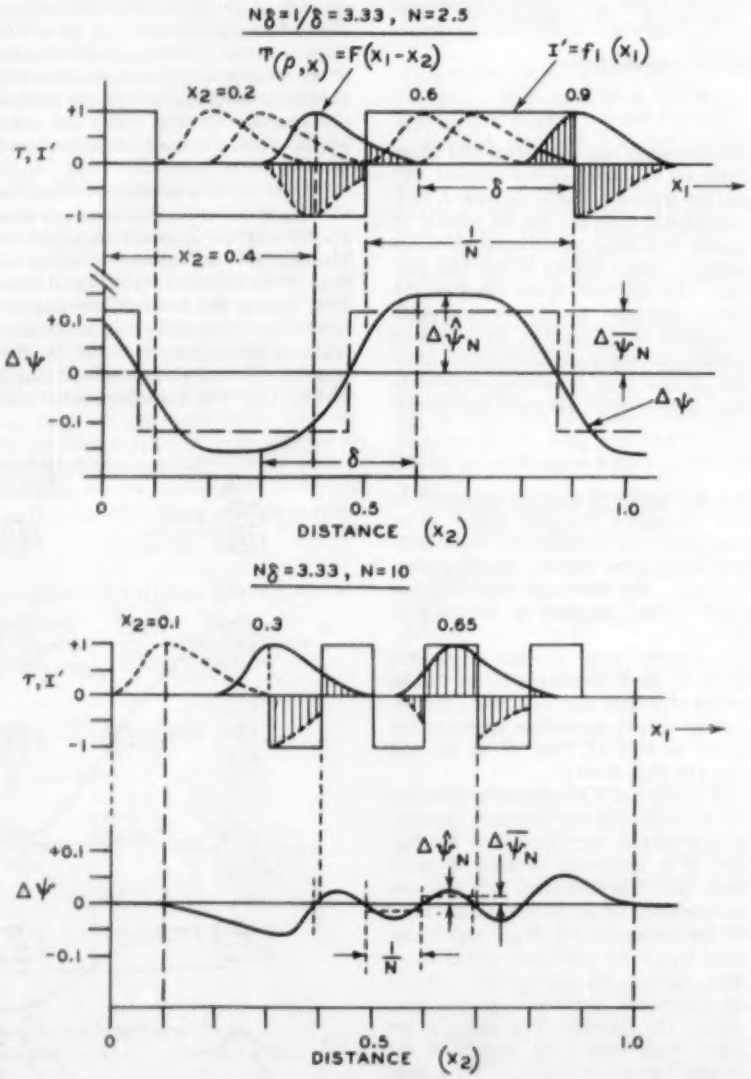


Fig. 122. Evaluation of square-wave response by scanning square-wave function $f_1(x_1)$ with line-transmittance function $F(x_1 - x_2)$.

* Examples of this process are given in Refs. 4 and 5, and Fig. 84, Part III.

tained by scanning the step function with the line-transmittance function of the aperture. This "edge transition" is simply a plot (Fig. 121) of the area of the line-transmittance $T_\rho = F(\rho, -x)$ under the unit step as a function of x_2, normalized to give a final level change equal to ΔI_1 and expressed by

$$\Delta I_2 = Q(\rho, x_2) = \frac{1}{A}\int_{-\infty}^{x=x_2} T_{(\rho)}\,dx; \qquad A = \frac{1}{\Delta I_1}\int_{-\infty}^{\infty} T_{(\rho)}\,dx \tag{104}$$

The edge transition is antisymmetric or asymmetric when the point-image (aperture) and its line transmittance are symmetric or asymmetric respectively. In the frequency domain, asymmetric transitions indicate a phase-displacement of Fourier components. The edge transition is in general a function of aperture orientation (ρ) with respect to the edge, and apertures with circular symmetry only can be specified by a single edge transition. Differentiation of Eq. (104) furnishes *the slope or gradient of the transition function, which is obviously the line transmittance of the aperture.* The Fourier spectrum of the aperture may thus be computed from the differentiated edge transition $T_{(\rho)} = Q'(\rho, x_2)$. Because of these mathematical relations, a two-dimensional point-image or aperture can be specified in the space domain by its transmittance function ($\tau = f(\zeta, \eta)$, by its edge transitions $\Delta I_2 = Q(\rho, x_2)$, its line transmittance $T_{(\rho)} = Q'(\rho, x_2) = F(\rho, x)$; or in the frequency domain by its Fourier spectra r_ψ, $\theta = g(\rho, N)$.

Square-Wave Response: The image intensity functions obtained from square-wave test objects (normal line patterns) can be computed by scanning square-wave functions with the line-transmittance function as illustrated in Fig. 122. They may also be constructed by superposition of positive and negative edge transitions. Square-wave image functions $\Delta\psi = f(x)$ can be synthesized by Fourier series with coefficients and phase angles obtained from the sine-wave spectrum of the aperture.

$$\Delta\psi = f(x) = \frac{4}{\pi}\sum_{p=1,3,5,\ldots}^{\infty}\frac{1}{p} r_{\psi(Np)} \cos\left(p\pi Nx + \theta_{(p)}\right) \tag{105}$$

The image waveform approaches the object function, i.e. a square wave, when the aperture is small compared to the length of one half cycle ($N \ll N\delta$) and, depending on the aperture type, may change to trapezoidal, triangular, sinusoidal, or complex waveforms when the line-number is increased (compare Fig. 122). Omitting again the steady component, the amplitude $\Delta\bar{\psi}$ of the *variational* image flux has no fixed relation to the average value $\Delta\bar{\psi}$ in the half-waves of the variational flux as for

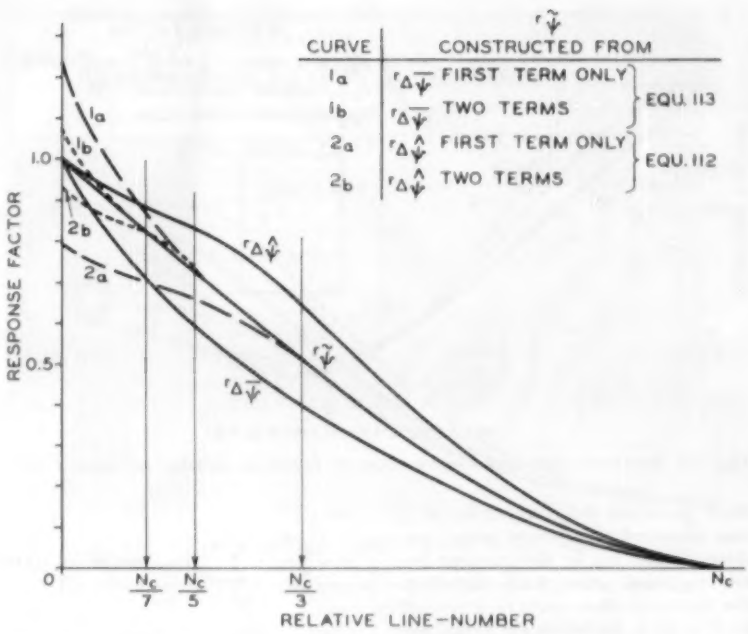


Fig. 123. Construction of sine-wave spectrum $r_{\bar{\psi}} = g(N/N_c)$ from square-wave response characteristics ($r_{\Delta\hat{\psi}}$ or $r_{\Delta\bar{\psi}}$).

sine-waves, but depends on the harmonic components of the wave-form. Both values can be measured using constant amplitude square-wave objects and, when normalized to unity at $N = 0$, represent square-wave response factors.[5]

The square-wave amplitude response factor $r_{\Delta\hat{\psi}}$ is defined by

$$r_{\Delta\hat{\psi}} = \Delta\hat{\psi}_{(N)}/\Delta\hat{\psi}_{(N=0)} \tag{106}$$

The square-wave flux response factor $r_{\Delta\bar{\psi}}$ is defined by

$$r_{\Delta\bar{\psi}} = \Delta\bar{\psi}_{(N)}/\Delta\bar{\psi}_{(N=0)} \tag{107}$$

Where $\Delta\bar{\psi}$ is the average half-wave intensity of the variational flux-wave and may hence be measured with a rectifier-type meter.

Relations Between Sine-Wave and Square-Wave Response Factors: In all cases (with or without phase shift) the last two-thirds of the line-number spectrum can only contain pure sine waves. It follows that for

$$N \geq N_c/3, \qquad r_{\Delta\hat{\psi}} = \frac{\pi}{2} r_{\Delta\bar{\psi}} \tag{108}$$

and with (105)

$$r_{\Delta\hat{\psi}} = \frac{4}{\pi} r_{\bar{\psi}} \text{ and } r_{\Delta\bar{\psi}} = \frac{8}{\pi^2} r_{\bar{\psi}} \tag{109}$$

At line-numbers between $N_c/3$ and $N_c/5$ the third harmonic ($p = 3$ in Eq. (105)) must be added vectorially to the fundamental; below $N = N_c/5$, both 3rd and 5th harmonics, and so on. For the condition of zero phase distortion $\theta_{(p)} = p\theta$, ($p = 1, 3, 5$), which is obtained with symmetrical apertures, the square-wave amplitude $a_{\Delta\bar{\psi}(N)}$ at the center of the half wave may be computed accurately from the series

$$a_{\Delta\bar{\psi}(N)} = \frac{4}{\pi}\sum_{p=1,-3,5,-7,\ldots}\frac{1}{p} r_{\bar{\psi}(pN)}, \tag{110}$$

This amplitude is equal to the peak amplitude factor $r_{\Delta\hat{\psi}}$ when the sine-wave spectrum has a gradual cut-off preventing overshoots at edges, which requires that the aperture transmittance never be negative.

The square-wave flux response is given accurately in all cases by

$$r_{\Delta\bar{\psi}(N)} = \frac{8}{\pi^2}\sum_{p=1,3,5,\ldots}\frac{1}{p^2} r_{\bar{\psi}(pN)}, \tag{111}$$

Conversely, the sine-wave response factors may be computed from the center amplitude of the square-wave response starting with $N = N_c$ and Eq. (109) down to $N = N_c/3$; and then further down towards $N = 0$ by progressively adding odd harmonics as expressed by

$$r_{\bar{\psi}(N)} = \frac{\pi}{4} a_{\Delta\bar{\psi}(N)} + \frac{1}{3} r_{\bar{\psi}(3N)} - \frac{1}{5} r_{\bar{\psi}(5N)} + \ldots \tag{112}$$

or

$$r_{\bar{\psi}(N)} = \frac{\pi^2}{8} r_{\Delta\bar{\psi}(N)} - \frac{1}{3^2} r_{\bar{\psi}(3N)} - \frac{1}{5^2} r_{\bar{\psi}(5N)} - \ldots \tag{113}$$

The first term of Eqs. (112) and (113) is shown by broken lines in Fig. 123

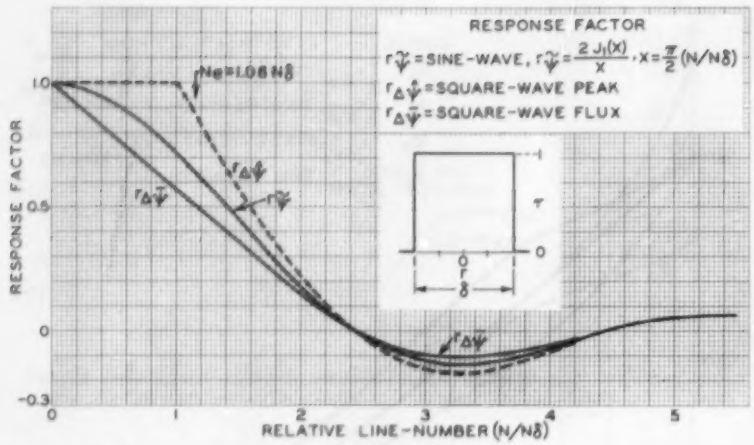


Fig. 124. Sine-wave and square-wave response factors of circular aperture, $\tau = 1$.

which illustrates the construction of $r_{\downarrow}$ from measured square-wave center amplitude factors $a_{\Delta\downarrow}$ or flux response factors $r_{\Delta\downarrow}$ and zero phase distortion. The first term alone gives $r_{\downarrow}$ accurately for $N > N_c/3$. Including the second and third terms, $r_{\downarrow}$ becomes accurate for $N > N_c/7$. Inspection shows that the series Eq. (113) converges much more rapidly than that of Eq. (112) so that fewer terms are necessary for good accuracy when $r_{\downarrow}$ is converted from $r_{\Delta\downarrow}$, as demonstrated by the dotted curves in Fig. 123. When phase distortion has been neglected, Eq. (112) will usually give higher values and Eq. (113) lower values than the correct sine-wave response. When the phase angles are known, $r_{\Delta\downarrow}$ can be computed directly with

$$r_{\Delta\hat{\downarrow}} = \frac{8}{\pi^2}\sum_{(p\,=\,1,\,3,\,5,\,\ldots)}^{1} \frac{r_{\downarrow(p,N)}}{p^2}\cos(p\theta_i - \theta_p) \quad (114)$$

also

$$r_{\downarrow} = \frac{\pi^2}{8} r_{\Delta\hat{\downarrow}} - \sum_{(p\,=\,3,\,5,\,7,\,\ldots)}^{1} \frac{r_{\downarrow(p,N)}}{p^2}\cos(p\theta_i - \theta_p) \quad (115)$$

The sine-wave response factor $r_{\downarrow}$ and square-wave response factors $r_{\Delta\hat{\downarrow}}$ and $r_{\Delta\bar{\downarrow}}$ of several apertures are shown in Figs. 124 to 127. The difference between center amplitudes and square-wave peak amplitudes is illustrated in Fig. 127 for an electrical spectrum having sharp cutoff.

6. Equivalent Passbands N_e and Apertures δ_e

It is often desired to indicate the properties of an aperture process by a single number. In the space domain such a number represents basically a length which specifies an aperture dimension or length of its edge transition. In the frequency domain the number specifies a "frequency" or a line-number which has the dimension length^{-1}. Because of the variety of possible aperture shapes and transmittance functions, it is to be expected that a single number must refer to a normalized aperture shape or spectrum, and that its evaluation will require some form of integration of actual aperture characteristics. The number so obtained is by necessity an *equivalent* which is exact in terms of the mathematical operation by which it is obtained, but a compromise when specific properties of an aperture process are considered. In selecting a basis for equivalence one must keep in mind that an aperture process is generally used to reproduce not one, but a variety of complex object functions, describing contours or edges with various shapes, intensity differences, and orientations. The corresponding Fourier expressions represent an infinite variety of sine-wave combinations with different line-numbers, amplitudes, and phase-relations, and even one particular series of sine-wave terms with specified line-numbers and amplitudes may be combined to give a variety of widely different "waveforms" by merely changing the phase relation of the components. These considerations indicate that a representative total of the aperture response might well be obtained by integration of its "*energy spectrum*" $r_{\downarrow}^2 = g^2(\rho,N)$, the squaring operation being required if, as an average, a random phase relation is assumed. This integral

$$N_{e(\rho)} = \int r_{\downarrow(\rho)}^2\, dN = \int (g(\rho,N))^2 dN \quad (116)$$

which has the dimension length^{-1} has been introduced in Part II (pp. 191 to 198) and is equal to the area under the squared sine-wave spectrum. Because a spectrum with constant response ($r_{\downarrow} = 1$) extending to a line number N_e contains the same total sine-wave energy, the measure $N_{e(\rho)}$ *specifies an equivalent rectangular passband* of the aperture in the frequency domain (see Fig. 128). A corresponding measure in the space domain is its reciprocal $s_\rho = l/N_e$, (l = length unit) which is the length of an *equivalent rectangular line-transmittance function* (T = 1) of the aperture. The significance of these equivalents is more fully understood from the mathematical relations between the frequency domain and the space domain.

The integral $N_{e(\rho)}$ (Eq. (116)) can be measured directly with a square-law meter by letting the aperture scan an ideal grain structure which is random in the scanning direction (x) and uniform in the y-direction (see Fig. 48, Part II), because such a pattern contains an infinite spectrum of constant amplitude sine-waves in random phase relation. Other methods for a direct measurement of the equivalent passband are indicated by the following relations. The squared

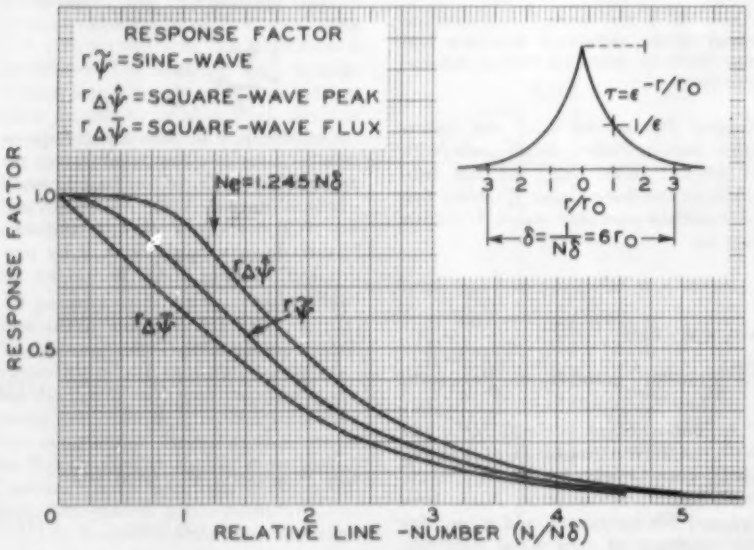


Fig. 125. Sine-wave and square-wave response factors of circular aperture, $\tau = \epsilon^{-r/r_0}$.

aperture response to random intensity variations has been discussed in Part II (Eq. (27)) and $N_{e(\rho)}$ is equal to the *area under the squared line-transmittance function* $T_\rho = F(\rho,x)$ when the aperture volume is normalized to unity:

$$N_{e(\rho)} = \frac{1}{A^2}\int_{-\infty}^{\infty}[F(\rho,x)]^2dx \quad (117)$$
$$A = \int F(\rho,x)dx$$

Because of the relations discussed in Section A3, this area and N_e are also equal to the *integral of the squared slope values* $Q'(\rho,x_2)$ *of the normalized edge transition:*

$$N_{e(\rho)} = \frac{1}{A^2}\int_{-\infty}^{\infty}[Q'(\rho,x_2)]^2dx_2 \quad (118)$$
$$A = \int F(\rho,x)dx$$

Furthermore, because of Eq. (96), N_e can be expressed *in terms of the aperture transmittance:* $\tau = f(\zeta,\eta) = f(\rho,x,y)$:

$$N_{e(\rho)} = \frac{1}{V^2}\int_{-\infty}^{\infty}dx\left[\int f(\rho,x,y)dy\right]^2 \quad (119)^*$$
$$V = \int\int f(x,y)dxdy$$

The normalizing factors A and V in these equations express the "volume" of the aperture. (The factor A in Eq. (118) becomes unity when the edge-transition function $Q(\rho,x_2)$ has the limits zero and unity.)

It is obvious that apertures having circular symmetry have an equivalent passband which is independent of orientation. All other apertures have many equivalent passbands $N_{e(\rho)}$. The reciprocal $1/N_{e(\rho)}$ specifies an effective length in the scanning direction; i.e., the length of an *equivalent rectangular line-transmittance function* $T = F(x) =$ constant.

The true line-transmittance function of the aperture may have a different shape and length s_e which can be related to its N_e = value by the expression

$$s_e = Kl/N_{e(\rho)} \quad (120)$$

where l is the unit of length and K is a shape factor computed from and indicating a line-transmittance or spectrum of particular shape (see Part II, Table VII). An aperture having a (sin x)/x type spectrum has a rectangular line-transmittance and hence a shape factor $K = 1$. This shape factor is common to a group of apertures (see Fig. 129) including all apertures with uniform transmittance having a constant width (y) perpendicular to the scanning direction. A triangular line-transmittance has a shape-factor $K = 1.5$ which indicates a different group of apertures as shown in Fig. 129. An aperture base shape can, therefore, be recognized only when equivalent passbands are given as a function of direction. Identical spectra and values $N_{e(\rho)}$ in any direction obviously indicate a circular aperture. An elliptical or rectangular aperture is recognized by having one maximum $N_{e(0°)}$ and one minimum $N_{e(90°)}$ in perpendicular directions.

* Compare the evaluation and expressions for N_e given in Part II, pp. 191–198.

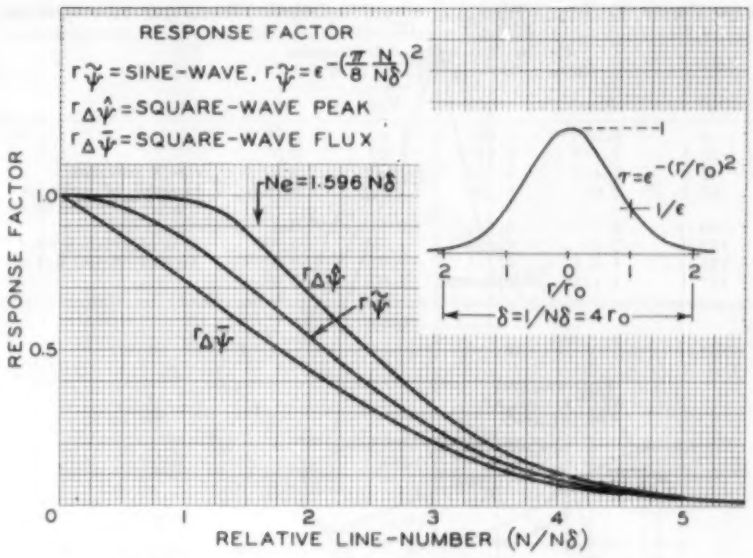


Fig. 126. Sine-wave and square-wave response factors of circular aperture, $\tau = \epsilon^{(r/r_0)^2}$.

The geometric meaning of equivalent lengths is illustrated in Figs. 130 and 131 for an elliptical and a rectangular aperture. The values $N_{e(\rho)}$, computed with Eq. (117) (see also Fig. 131), are listed in Table XXV. The corresponding lengths s_ρ computed with Eq. (120) for circular and rectangular shape factors $K = 1.08$ and $K = 1$ respectively are indicated in Figs. 130 and 131 by arrow-headed lines. It is evident that these effective lengths are overall x-dimensions of the aperture in the scanning direction and not necessarily diameters. In the elliptical example, the figure inscribed between all x-dimensions (s_ρ) is the true aperture because the shape factor of an ellipse is $K = 1.08$ and invariable. The equivalent lengths computed with $K = 1$ for the rectangular aperture coincide with the actual aperture dimensions for $\rho = 0°$ and 90° only, but not in other directions where the shape factor is not unity as assumed. It is not difficult to see that the true shape factor cannot always be recognized from the spectrum or line-transmittance shapes. This does not decrease the general significance of the equivalent measure.

It is in fact often desirable to condense

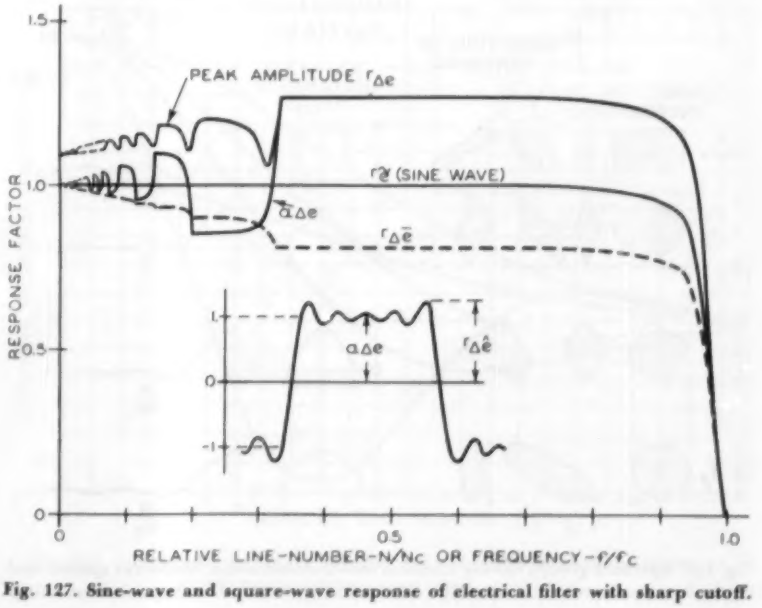


Fig. 127. Sine-wave and square-wave response of electrical filter with sharp cutoff.

TABLE XXV. Equivalent Passbands $N_{e\rho}$ and Equivalent Lengths s_ρ of Two Apertures.

	Ellipse (K = 1.08)		Rectangular (K = 1.)		
$\rho°$	$N_{e(\rho)}$	s_ρ	$N_{e(\rho)}$	s_ρ	
0	1.08	1.00	1.0	1.00	
22.5	1.175	0.917	1.03	0.97	
45.0	1.415	0.765	1.22	0.82	τ = 1, constant
67.5	2.05	0.526	1.785	0.56	Lengths of sides or axes: 1.0 and 0.4
90.0	2.7	0.4	2.5	0.4	
112.5	2.05	0.526	1.785	0.56	Area of rectangle: 0.4
135.0	1.415	0.765	1.22	0.82	Area of ellipse: 0.1 π
157.5	1.175	0.917	1.03	0.97	

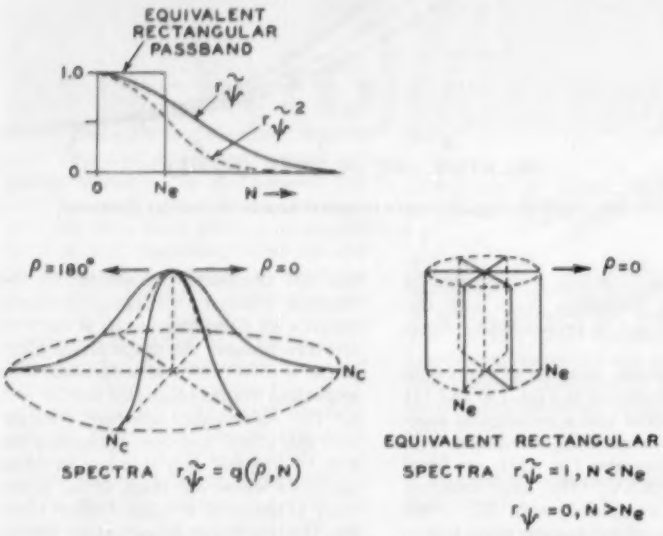


Fig. 128. Sine-wave spectra and equivalent passbands (N_e) of an aperture having circular symmetry.

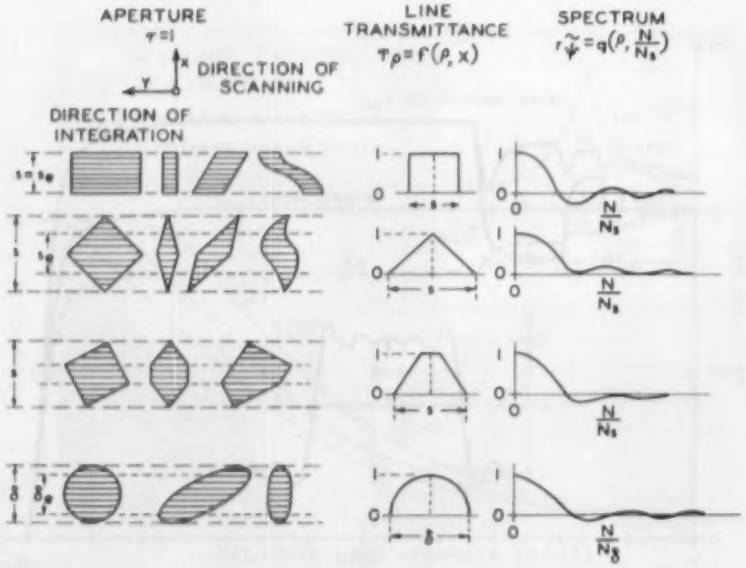


Fig. 129. Aperture groups having identical line-transmittances, sine-wave spectra and equivalent passbands for a specified orientation (ρ) to the direction (x) of scanning.

the measures $N_{e(\rho)}$ into one single equivalent $\bar{N}_e$ designating an *equivalent symmetric aperture* (see Part II, p. 193). Given only the perpendicular values $N_{e(0°)}$ and $N_{e(90°)}$ representing maximum and minimum values, this single equivalent is approximated by their geometric mean:

$$\bar{N}_e = (N_{e(0°)} N_{e(90°)})^{\frac{1}{2}} \qquad (121)$$

Given a number of values specifying the function $N_{e(\rho)} = F(\rho)$, this equivalent passband $\bar{N}_e$ is obtained as the rms value

$$\bar{N}_e = \left(\frac{1}{\pi}\int_0^\pi (F(\rho))^2 d\rho\right)^{\frac{1}{2}} \qquad (122)$$

These methods of averaging $N_{e(\rho)}$ values are indicated dimensionally (N_e is a line-number) and agree with one another. The integral in Eq. (122) may be approximated by a sum of at least four values (0°, 45°, 90°, 135°).

The equivalent length

$$\bar{s} = Kl/\bar{N}_e \qquad (123)$$

designates the length of a square aperture (K = 1, τ = 1) or the diameter δ_e of a circular aperture (having constant or variable transmittance (τ) as indicated by the factor K), which have the same value $\bar{N}_e$ as the actual aperture. The equivalent circular aperture has one equivalent spectrum, edge transition, and transmittance as defined by Eqs. (117), (118), and (119).

It was pointed out in Part II C-3 that the measure $\bar{N}_e$ may differ somewhat from a measure $\bar{N}_0$ derived by the sampling of an ideal grain pattern which is random in all directions and has an infinite spectrum of constant amplitude. The measure $\bar{N}_0$ is truly independent of aperture orientation. The differences arise from the use of sine-wave spectra obtained by the scanning of practical one-dimensional "line"-patterns. The area $A = \bar{s}^2\pi/4$ of the equivalent circular aperture may, therefore, differ somewhat from the exact sampling area of the aperture. For example, both Eqs. (121) and (122) give the value $\bar{N}_e$ = 1.71 for the elliptical aperture in Table XXV and Eq. (123) furnishes $\bar{s}$ = 1.08/1.71 = 0.632 for an equivalent circular aperture having τ = 1. The computed area A = 0.1π is equal to the true area of the elliptical aperture. In the rectangular case (see Table XXV) the equivalent

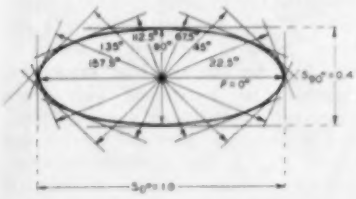


Fig. 130. Equivalent lengths (s_ρ) of an elliptical aperture.

$\bar{N}_e = 1.58$ from Eq. (121) gives the true area $A = 0.4$ with the shape factor $K = 1$. Equation (122) furnishes $\bar{N}_e = 1.53$ requiring a value $K = 0.96$ to obtain the true area, because of the variable trapezoidal shape of the line-transmittance for directions ρ other than 0° or 90°.

The equivalent passband $N_{e(p)}$ of a multistage process is given accurately by the integral

$$N_{e(p)} = \int_0^\infty (r_{g_1} r_{g_2} \ldots r_{g_n})^2 dN \quad (124)$$

Because of the nature of the response characteristics of practical two-dimensional apertures (lenses, films, television tubes), it has been found that the equivalent sampling area of a combination of these apertures can be evaluated with usually less than 5% error by simply adding the equivalent aperture areas of the components, or as expressed in terms of equivalent aperture diameters:

$$\delta_u \leq (\delta_1^2 + \delta_2^2 + \ldots \delta_n^2)^{\frac{1}{2}} \quad (125a)$$

also:

$$1/N_{e(p)} = (1/N_{e1}^2 + 1/N_{e2}^2 + \ldots + 1/N_{en}^2)^{\frac{1}{2}} \quad (125b)$$

Equation (125) is exact for circular apertures with error curve transmittance $\tau = \epsilon^{-(r/r_0)^2}$ which have an error curve spectrum (Fig. 126). The spectrum of a system of two-dimensional apertures tends to approach this form and can therefore be used (see Part II) as an *equivalent standard response characteristic* having a line-number scale $N = N_e/1.6$.

The simplified method can lead to larger errors when components having constant or rising frequency spectra are included such as electrical amplifier circuits (see Part III). In these cases the apertures of the system are grouped into "normal" optical apertures which can be combined by using Eq. (125) and replaced by a standard equivalent error curve spectrum, and into special apertures having "abnormal" spectra, which are combined with the equivalent error curve spectrum by multiplication (Eq. (124)).

7. Frequency Spectrum of Multiple Apertures (Misregistry, Diffraction Grating)

The transmittance function of a group of apertures having a fixed location relative to one another is the sum of the individual transmittance functions. The combined spectrum $g(\rho,N)$ of the aperture group in a given direction (ρ) is the vector sum of the individual spectra in this direction, modified in amplitude according to Eq. (103). The phase difference $\theta_1 - \theta_2$ between the sine-wave response of two apertures vanishes at $N = 0$ and increases linearly with N. Its scalar value is easily determined from the distance $d_{(x)}$ of the aperture centers in the scanning direction which

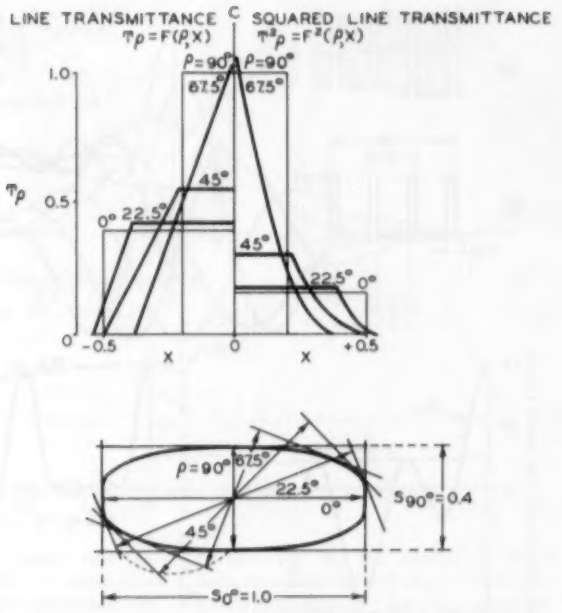


Fig. 131. Line-transmittances ($\tau\rho$) and their squared values τ^2 a rectangular aperture, and equivalent lengths $s_\rho = K1/N_e$ for K = 1.

corresponds to the line-number $N_{d(x)} = 1/d_{(x)}$ at which $\theta_1 - \theta_2 = \pi$.

Misregistry of two identical images represents the case of two identical apertures displaced by a certain distance $d_{(x)}$.* The two aperture spectra are identical and their flux contributions and amplitude scale factors are hence 0.5 as illustrated in Fig. 132 for an error curve type spectrum and for four aperture distances: $d_{(x)} = 0$, $\delta/3$, $\delta/2$ and δ. It is seen that the total response becomes zero at the line-numbers $N/N\delta = 3$, 2, and 1 respectively, at which $\theta_1 - \theta_2$ is equal to π; the response of one aperture cancels the response of the other aperture by complete interference. The phase-angle θ of the total response measured with respect to the center of the combined aperture is $\theta = 0$ below the first zero. It changes abruptly to $\theta = \pi$ for the range between the first and second zero, back to $\theta = 0$ between the second and third zero, and so on. It can be seen by inspection that the re-

* An intentional misregistry of this type is the widening of a kinescope spot by "spot wobble."

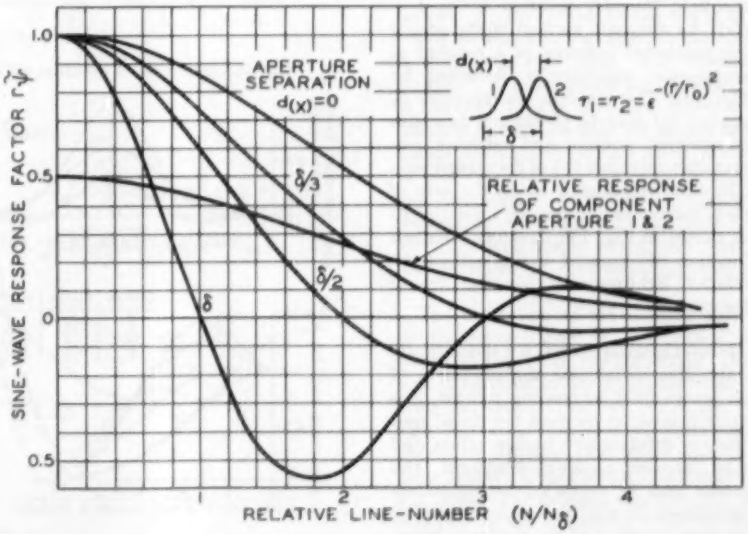


Fig. 132. Interference sine-wave spectra obtained with two identical apertures in misregistry (square-wave "spot wobble").

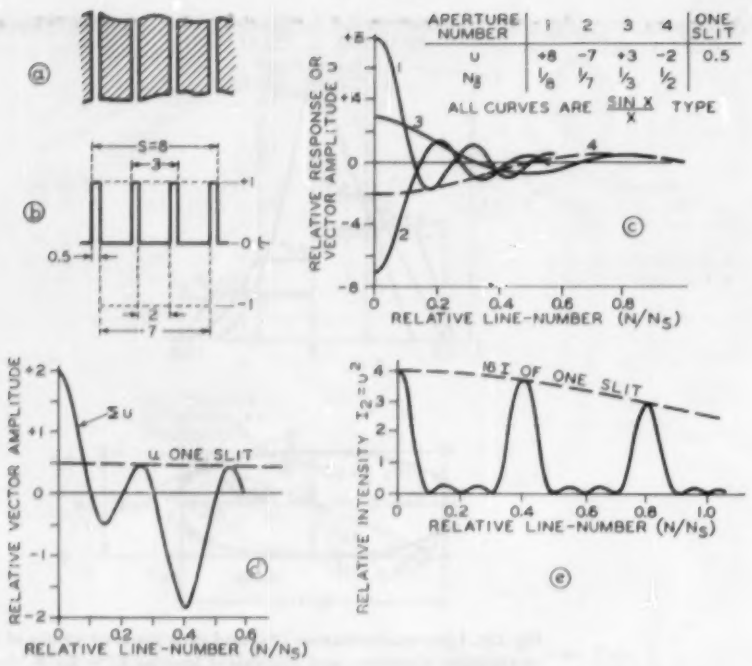


Fig. 133. Synthesis of interference spectrum of an optical grating as the squared sum of component spectra.

sponse decreases in the same manner as a single aperture enlarged in the scanning direction, except for the spurious response beyond the first zero, which could not occur with a single aperture.

A *diffraction grating* represents the case of a large number of identical rectangular apertures uniformly spaced. The combined aperture spectrum computed in the same manner represents, in this case, the relative amplitude of the electric vector $U = f_1(x)$ in the image plane (discussed later in Sect. B, 1) and its square, the light intensity function $U^2 = I = f(x)$. An alternate method of computing the combined response of a number of rectangular apertures is illustrated by Fig. 133. The multiple slot-aperture or grating (a) may be considered as a sum of centered positive and negative rectangular apertures (b) of decreasing size. The total response is hence the sum of their corresponding $(\sin x)/x$ spectra (c) as shown in Fig. 133, and the obtained function (d) squared is the well-known relative light-intensity function (e) of the grating.

Aperture Correction: While it is theoretically impossible to increase the resolution of an image by a succeeding process, it is quite feasible to increase the detail contrast to substantially higher values and thus increase apparent sharpness. The image may be corrected by equivalent operations in the space- or frequency-domain. In terms of the spectrum representation of the point-image or aperture, a decreasing amplitude response $r_f = f(N)$ can be made more uniform (a) by multiplication with the spectrum of a succeeding process having a rising amplitude characteristic (see Fig. 81, Part III), or (b) by addition (and subtraction) of shorter spectra obtained by partial integration (diffusion) or differentiation of the original spectrum (Refs. 6 and 7; see also Fig. 84 of Part III). It is obvious that high "frequencies" beyond the resolution limit of the original aperture cannot be recovered, although they may be introduced artificially by a retouching or "crispening" process.[8] In the time- or space-domain representation an impulse or point-image size is not reduced in proportion, but its transmittance function is altered by addition of derived functions to emphasize the high-frequency end of its spectrum. *Aperture correction in photographic processes* is obtained by subtraction and addition of shorter low-pass spectra obtained by integration; i.e. by subtraction and addition of larger point-images. A simple correction process is illustrated in Fig. 134a by the corresponding line transmittances T_1 and T_2 and their difference $T_1 - T_2$. Subtraction means that T_2 is an aperture having negative transmittance values. These are possible with reference to a positive transmittance (density) level which is not shown in Fig. 134a. The aperture line-transmittance $-T_2$ is obtained by diffused contact printing or by a 1 to 1 out-of-focus projection of the original, which produces a negative image. Superimposition of this negative, termed "mask," in registry with the original (assumed to be transparencies) causes the subtraction $T_1 - T_2$ in a succeeding printing process.

The optimum value T_2 and the degree of diffusion (δ_2 of aperture 2) can be determined readily from the corresponding line-number spectra shown in Fig. 134b. The aperture spectra (and transmittances) are approximated by error curves. Curve 1 in Fig. 134b represents the spectrum of the original image (δ_1), and 2 is the shorter spectrum of the diffused print (δ_2) differing from curve 1 in amplitude scale and line-number scale, but not in shape. With two error curves drawn on log-log paper, a scale change in either coordinate is obtained simply by shifting one curve against the other. The shifts can then be adjusted so

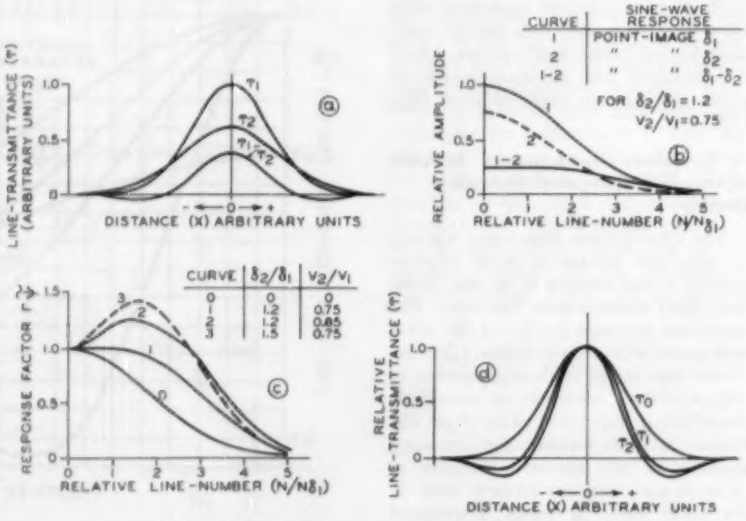


Fig. 134. Aperture correction by subtraction of shorter low-pass spectra (larger negative apertures, "masking").

that the numerical difference ($r_{g1} - r_{g2}$) is substantially constant over a considerable part of the spectrum as shown by Fig. 134b. The shift in the frequency scale furnishes the aperture diameter δ_2 from $N_{s1}/N_{s2} = \delta_2/\delta_1$ and the shift in amplitude scale is proportional to the "volume" of the apertures:

$$\text{at } N = 0, \qquad r_{g2}/r_{g1} = V_2/V_1$$

It follows that the transmittance scales T or τ are obtained with

$$T = c r_{g(0)} N_\delta$$
$$\tau = c r_{g(0)} N_\delta^2$$

where c is a constant.

Some of the frequency spectra obtainable by varying ratios of V_2/V_1 or δ_2/δ_1 are illustrated in Fig. 134c. Corresponding line-transmittances are shown by Fig. 134d.

Constancy of amplitude response over a larger range requires multiple masking (see Fig. 84 of Part III) and synthesis of a $(\sin x)/x$ type transmittance, which causes transient ripples in edge transitions as discussed in Part III for electrical circuits (compare Fig. 85 of Part III). Simple electrical "high-peaking" circuits cause phase distortion and asymmetric impulse shapes which must be corrected by the addition of phase-correcting circuits. Phase distortion in masking processes is produced by misregistry.

Increased uniformity of the sine-wave spectrum and a sharper cutoff can also be achieved by the *addition of spectra derived by repeated differentiation* of the image-intensity function.[7] To be operative, the function $I_2 = Q(x)$, as well as its derivatives Q', Q'', Q''', must be continuous. This requirement is met by most practical processes which tend to have apertures with an error-curve line-transmittance $T_1 = Q'(x) = (1/\sqrt{\pi})e^{-x^2}$. It is seen from Fig. 135 that all even derivatives are odd functions when the original function is an odd function such as the edge transition $I_2 = Q(x)$. The even derivatives may be combined to form a corrective function

$$I_d = -c_2 Q''(x) + c_4 Q''''(x) - c_6 Q^{VI}(x) + \ldots \quad (126)$$

When added to the original function $I_2 = Q(x)$ with suitably chosen coefficients c_2, c_4, c_6, the resultant corrected function $I_2 + I_d$ can be made to approach the integral $\int [(\sin x)/x]dx$, or any one of the functions shown in Fig. 89a. An example is shown in Fig. 136a. The original transition I_2 corresponds approximately to curve 5 of Fig. 89. The corrective function I_d contains only the second and fourth derivatives which, when added to the original function, give a good approximation to curve 2 of Fig. 89 corresponding to a substantially uniform spectrum with sharp cutoff and threefold increase in equivalent bandwidth (N_e).

The correction of the impulse signal or line-transmittance $T = f(x)$ is illustrated by Fig. 136b. The correcting function is again as in Eq. (126) the sum of even derivatives; $Td = -c_2 f''(x) + c_4 f''''(x) - c_6 f^{VI}(x) +$, which is approximated by the first two terms with the same numerical coefficients c_2 and c_4 as in Fig. 136a. The original function $f(x)$ in this case is the derivative $Q'(x)$ of the edge transition, and an even function and its even derivatives are likewise even functions. The corrected line-transmit-

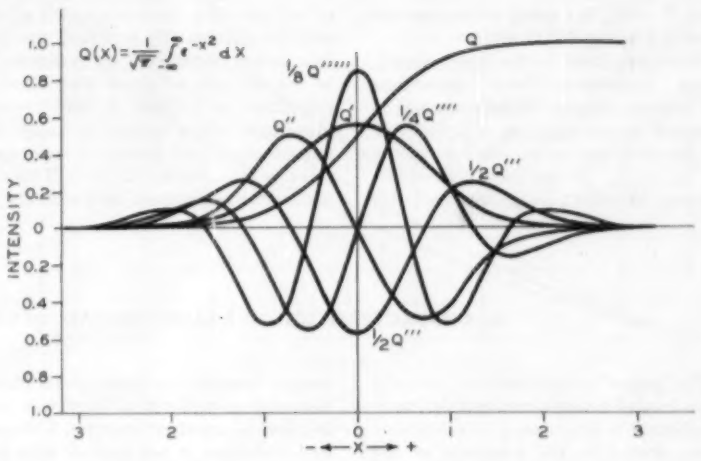


Fig. 135. The first five derivatives of the error integral.

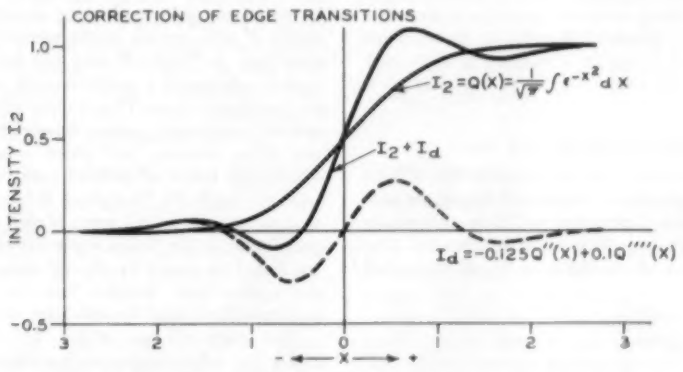
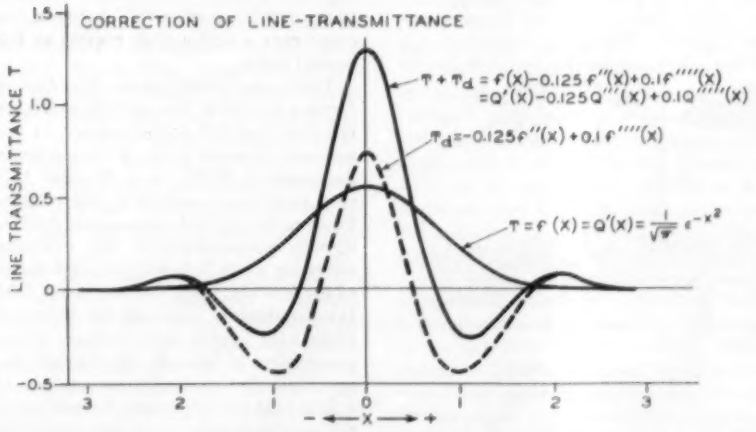


Fig. 136a. Correction of edge transition by addition of even derivatives.



136b. Correction of line-transmittance (impulse) by addition of even derivatives.

tance $T + T_d$ is a good approximation of curve 2 in Fig. 88, Part III.

Phase distortion, in the image signal, causes asymmetric edge transitions and impulse shapes. Phase distortion is corrected by the addition of a series of *odd derivatives* having suitable coefficients (c_1, c_3, etc.). A complete correction requires, therefore, in general a series of odd and even derivatives with adjustable coefficients. In practice, the first four or five derivatives are sufficient. It is not difficult to prove that aperture correction by addition of derivatives is inoperative when applied to image signals obtained with sharply defined apertures (τ = constant, $\cos^2$, etc.). This limitation can be removed by first changing the aperture transmittance by diffusion (low-pass filter) to permit subsequent correction by derivatives.

It may be said in conclusion that the three methods of aperture correction can give identical results. None of them can restore parts of the spectrum which have been lost in a preceding integrating process.

B. CHARACTERISTICS OF IMAGE-FORMING DEVICES AND SYSTEMS

The "perfect" image is defined optically as an image in which the light-intensity distribution is determined by diffraction alone. Stated in the language of the communication engineer, a "perfect" optical image has a Fourier spectrum determined by the characteristics of its cutoff filter alone, the sine-wave response factor of its transducing elements being unity within the passband of the system. In analogy with electrical systems, the cutoff filter of an optical lens is the lens stop which limits the optical passband by diffraction, and the glass elements of the lens serve a purpose similar to the transducing elements of a wide-band amplifier in guiding electromagnetic "vibrations" through the system. The optical term "perfect" is, therefore, not applied to the lens as a whole but to aberration-free focusing elements which have a sine-wave response factor of unity. From a more general point of view, a "perfect system" is one in which the transducing elements *and* filter elements are designed as a unit, so that the sine-wave amplitude response of the entire system (which is the product of its component spectra) is without phase distortion and as uniform as consistent with the desired transient response. This general definition is not limited to a rectangular spectrum with abrupt cutoff, which is the mathematical concept of a perfect spectrum utilization. It does not seem impossible that this approach could also lead to optical designs with more desirable characteristics.

1. The "Perfect" Lens

The following discussion of the "perfect" lens is based on the well-established principles of wave theory and makes use of the aperture theory developed in preceding sections to compute the sine-wave spectra of optical instruments which depart in a number of ways from the electrical concepts of a perfect spectrum.

(a) *The Point-Image*

A point source of monochromatic light is a system of dipoles of atomic or molecular dimensions radiating spherically expanding electromagnetic waves. The system of dipoles is so small compared to the distance to the point of observation that it is not resolved, and appears therefore as a point source of radiation. The oscillator frequency is in the order of 600 million megacycles (λ = 0.0005 mm). The electromagnetic radiation reaches the lens-aperture as a plane-wave as indicated in Fig. 137.

According to Huygens principle, every point in a wave-front can be regarded as a secondary source of radiation. All secondary point sources oscillate in perfect synchronism and in phase. The plane of the lens aperture can, therefore, be treated as a source of cophasal radiation. The radiation may be grouped into beams of parallel rays, leaving at various angles θ' with respect to the normal ray direction. A "perfect" lens (L) focuses each ray-beam to a mathematical point on the image plane. The electric intensities at these image points, however, are not alike, because the phase relation within the beam of parallel rays varies with the angle θ'. This phase relation is that existing in a "reference plane" perpendicular to the beam, before it enters the lens. It is caused by the differences in the optical-path lengths between the aperture plane and the reference plane.

The lower left part of Fig. 137 illustrates the relative electric intensities in the reference plane at a particular instant for rays leaving the aperture plane at an angle $\theta' = \sin^{-1}(\lambda/\delta)$, which causes a phase difference of $\pm 180°$ between the outer rays a and e with respect to the central ray c.

The electric-intensity distribution forms a sine-wave line pattern which, in this case, has two half-waves within the aperture diameter δ, i.e., it has a relative line-number $N/N\delta = 2$. Because λ is very small compared to δ, the relative line-number of this sine-wave field is directly proportional to θ', and the reference plane has the area and shape of the lens aperture. The sine-wave field is not stationary but scans the reference plane with light velocity because of the progression of wave-fronts through the aperture. The *resultant vector amplitude at a focal point* on the image plane is hence the maximum value of the integral of the products of sine-wave field intensities and aperture chord lengths as expressed by

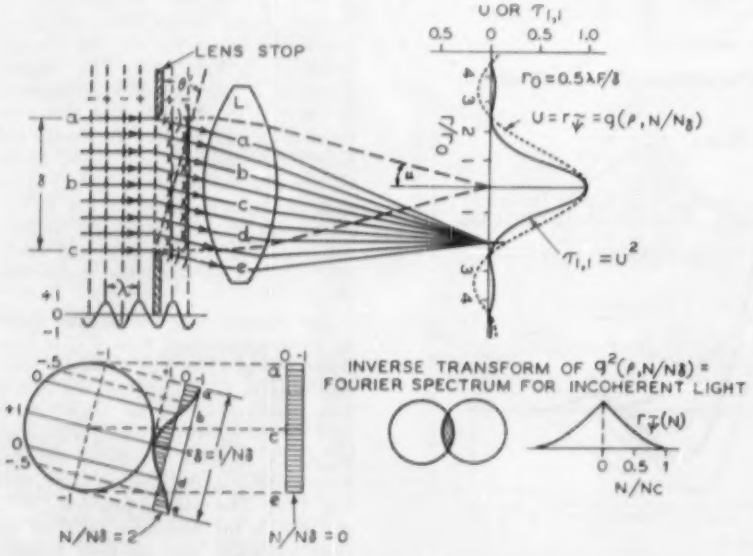


Fig. 137. Diffraction and "U-wave" at the lens stop, point image, and spectrum of the perfect lens.

Eq. (100). Its variation with θ' is recognized as the sine-wave response of the aperture to line-numbers $N/N\delta$ varying from zero to infinity. Stated mathematically, *the electric vector amplitude u at the image plane is the sine-wave spectrum (transform) of the lens aperture:*

$$U = \tau_{\mathfrak{F}}(N/N_\delta) = g(\rho, N/N_\delta) \quad (127)$$

This function describes the electric vector point-image.

The light intensity or relative energy is proportional to the square of the electric vector: $I \propto U^2$. *The transmittance function of the energy point-images is hence the squared sine-wave spectrum of the lens aperture:*

$$I = \tau = f(r/r_0) = g^2(\rho, N/N_\delta) \quad (128)$$

The energy point-image for a circular aperture is the "airy disc" or "star" image. The reference radius r_0 (see Fig. 137) for the point-image is established for $N = N_\delta$ from the trigonometric relations $\sin \theta' = 0.5\lambda/\delta$, and $\sin \theta' = \tan \theta' = r_0/F'$ (F' is the focal distance). Equating these two expressions furnishes the reference radius corresponding to N_δ of the aperture spectrum:

$$r_0^* = 0.5\lambda F'/\delta = \lambda/4 \tan u \quad (129a)$$

Equation (129a) is valid when $\tan u = \sin u$, i.e. for relative apertures $f: = F'/\delta \geqq 2$. When the half-angle u becomes large as in microscope objectives, Abbe's sine condition $n'r' \sin u' = nr \sin u$ must be fulfilled for conjugate object and image points at all lens zones, which results in the more general relation:

$$r_0 = \lambda/4n \sin u \quad (129b)$$

where n is the index of refraction of the medium in which the object is immersed ($n = 1$ for air) and u the half-angle of the cone of rays accepted by the aperture.

Vector amplitude and transmittance of the near axial vector and energy point images caused by diffraction and interference phenomena in a "perfect" lens are transforms and squared transforms of the lens aperture. Size and shape of these point images are therefore controlled by the form of the lens stop (round, elliptical, square, etc.) and can be modified further by changing the lens-stop transmittance ($\cos^2$, exponential, etc.). The modifications obtainable can be assessed by comparing the sine-wave spectra or the squared sine-wave spectra respectively of these apertures (compare preceding section and apertures #1 and #3 of Fig. 120).

The point image for off-axis points increases in both radial and tangential directions by scale factors depending on the angle μ included between image point and lens axis. In the tangential direction (perpendicular to the ray angle), the scale factor is $1/\cos \mu$ because of the increased focal distance ($F'_\mu = F_0/\cos \mu$). In the radial direction the image is stretched by the scale factor $1/\cos^2 \mu$, because of 1) the increase in focal distance to F'_μ, 2) the inclination of the image plane, and 3) because the aperture plane contracts by a factor $\cos \mu$ which results in a larger angle $\theta'_\mu = \theta'_0/\cos \mu$. The reference radius of the point-image is therefore in general for the radial coordinate:

$$\left.\begin{aligned} r_0^* &= 0.5\lambda(f:)/\cos^2 u, \quad \text{or} \\ r_0 &= \lambda/4N.A. \cos^2 \mu \\ \text{and for the tangential coordinate:} & \\ r_0^* &= 0.5\lambda(f:)/\cos u, \quad \text{or} \\ r_0 &= \lambda/4N.A. \cos \mu \end{aligned}\right\} \quad (130)$$

where $N.A. = n \sin u$ is the *numerical aperture* of the lens.

(b) Sine-Wave Response Characteristics of the Point Image.

Effects of Light Source: The sine-wave response characteristic of a point-image may be computed as in Section A by letting the line transmittance of the point image scan a series of sine-wave line patterns. The double integration, one parallel to the line direction to obtain the line transmittance, the other in the direction of scanning, is based on the assumption that contributions to the intensity of an image point from different point images can be added directly. A direct addition of light energies (I) from different points is permitted when the corresponding electric vectors ($U = \sqrt{I}$) have a *random phase relation.* This condition is obtained optically when different object points are illuminated by different point sources of light, or by an extended source, or in sequence by a single point source as in the kinescope of a television system. The illumination and radiation of different object points is then "*incoherent*" and incapable of interference. It follows that a simultaneous illumination of all points in an object plane by a single point source of light is a *coherent* illumination which can produce interference effects due to phase differences when the synchronous secondary radiation from different object points is combined. Coherent illumination is limited in practice to microscope objects and requires an addition of vectors (U) rather than relative energies (I) when computing point-image integrals (see further down).

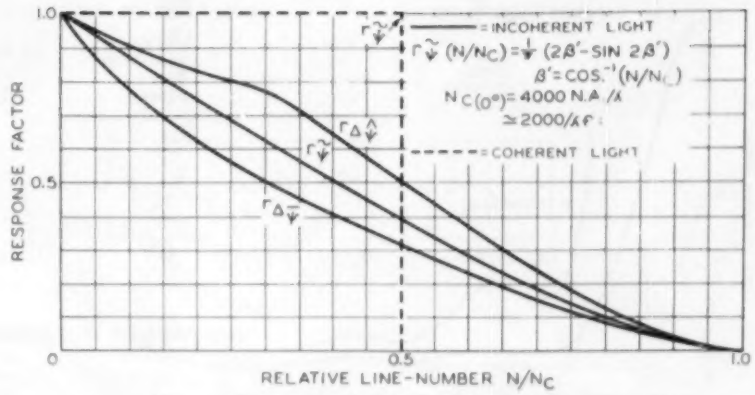


Fig. 138. Sine-wave spectrum of "perfect" lens, monochromatic light, on axis ($\mu = 0°$).

Sine-Wave Response for Incoherent Radiation: The sine-wave response characteristic of a point image is its Fourier transform which can be computed from its line transmittance. Because the energy point image of a "perfect" lens is equal to the squared transform of the lens aperture, the sine-wave spectrum of this point-image is more readily evaluated as the inverse transform of the product of two equal transforms, which corresponds to a *convolution* or cascading *of the lens aperture with an identical aperture* as discussed and illustrated by Fig. 112 in Sec. A.2. Except for a scale factor, the sine-wave response $\tau_{\mathfrak{F}}$ of a perfect lens is identical with the transmittance function $\tau_{1.1} = f(r/r_1)$ along a radius of the aperture body obtained by cascading the lens aperture with itself:

$$\tau_{\mathfrak{F}} = g(\rho, N/N_c) = \tau_{1.1} = f(\rho, r/2r_1) \quad (131)$$

where $2r_1$ = outside diameter of lens stop.

The lens aperture has normally a constant transmittance. The sine-wave spectrum (Eq. (131)) may then be computed with Eq. (95a). A circular lens stop with uniform transmittance gives the spectrum illustrated by the cascaded transmittance $\tau_{1.2}$ in Fig. 112, a circular stop with a blocked-out center gives a spectrum of the type shown in Fig. 115, while a rectangular stop will have a triangular spectrum in the directions parallel to its sides. There is no lens-stop shape or transmittance which will result in a rectangular spectrum with incoherent light, because two identical apertures in cascade will always have a transmittance peak $\tau_{1.1\max}$ when in register, corresponding to $N/N_c = 0$, and because the transmittance function of two apertures in cascade, would have to have negative

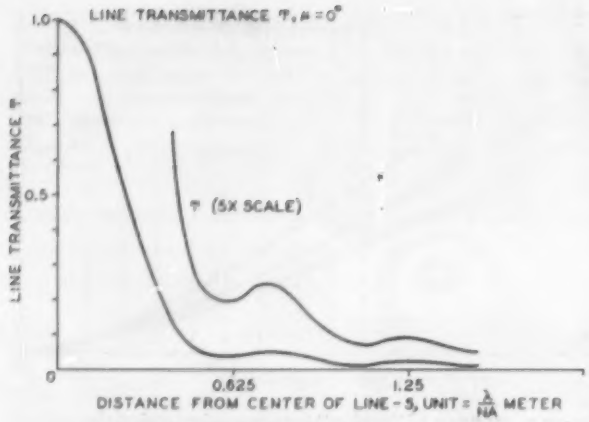


Fig. 139. Line-transmittance of "perfect" lens, monochromatic light, $\mu = 0°$.

portions which is impossible for energies. These conclusions are restricted to incoherent light and an optically "perfect" lens design meaning that the lens elements are free of aberrations, and have a constant sine-wave response factor of unity.

The reference line-number N_0 which corresponds to the diameter $2r_1$ of the effective lens stop is the reciprocal value of the reference radius r_0 of the point-image as discussed in connection with Eq. (129). Expressed in lines per millimeter and including off-axis positions of the point image, the limiting resolution $N_e = 1/r_0$ is obtained from Eq. (130). For the radial direction:

$$\left.\begin{array}{r} N_e^* = 2000\ (\cos^3\mu)/\lambda f{:}, \quad \text{or} \\ N_e = 4000\ N.A.\cos^3\mu/\lambda \\ \text{For the tangential direction } N_e^* = \\ 2000\ (\cos\mu)/\lambda f{:}, \text{ or } N_e = \\ 4000\ N.A.\ (\cos\mu)/\lambda \end{array}\right\} \quad (131a)$$

where

N_e = limiting resolution in (television) lines per millimeter
μ = angle included between image point and lens axis
λ = wavelength of light in microns
* limited to relative apertures $f{:} \geq f{:}2$

The sine-wave response ($r\downarrow$) as well as the square-wave response factors of the "perfect" lens are shown in Fig. 138 for monochromatic light and $\mu = 0°$. Its line-transmittance T, computed by a 10 term harmonic synthesis from this spectrum, is shown in Fig. 139.

In practice the object illumination is seldom monochromatic but extends over a range of wavelengths with varying relative energy which may be modified further by the spectral sensitivity of a photo sensitive image surface in a camera or the eye. Equations (130) and (131a) show that the radius of the point-image as well as the line-number scale of the sine-wave spectrum of the perfect lens (zero chromatic aberration) are functions of wavelength (λ). The sine-wave response for an extended wavelength range is, therefore, obtained by dividing the range into incremental sections and computing the sine-wave spectra for the center wavelengths of each section. After multiplying the response factors by the respective relative energy value of the section, the response for like line-numbers is added and finally normalized to give $r\downarrow = 1$ at $N = 0$. The sine-wave spectrum $r\downarrow$ as well as the square-wave response factors of the perfect lens computed for "white light" (constant energy spectrum from $\lambda = 0.4$ to 0.7μ, and zero outside these limits) are shown in Fig. 140.* The sine-wave spectrum obtained for a relative energy distribution equal to the luminosity curve of the eye is shown in Fig. 141. Comparison of these characteristics with Fig. 138 shows that the "white-light" response does not have a sharply defined resolution limit (finite slope) as obtained for monochromatic light, although the mathematical limit $N/N_e = 1$ occurs at a definite line-number, determined by Eq. (131a) for the shortest wavelength of the spectral range.

Sine-Wave Response for Coherent Radiation: Microscopic objects can be illuminated with coherent light from a point source. The direct addition of energy point-images is no longer permitted because of the fixed phase relations between vectors from different object points. In the simplest case, the illuminating point source is located on the optical axis and by means of a condenser the object is illu-

* The response characteristic, Fig. 45 in Part II, was obtained by an approximate method and should be replaced by the exact characteristic in Fig. 140.

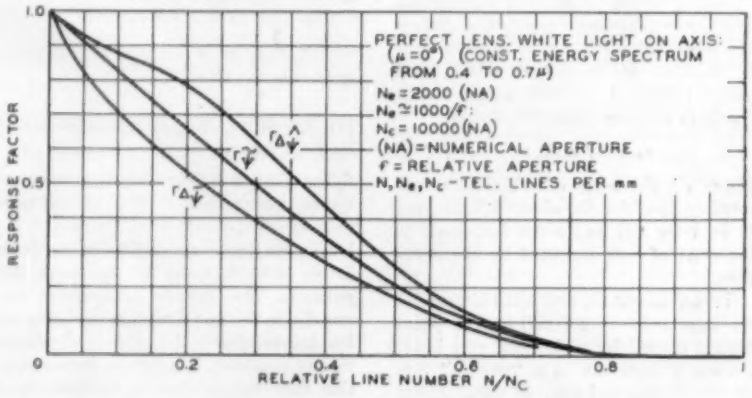


Fig. 140. Sine-wave spectrum of "perfect" lens, "white" light, $\mu = 0°$.

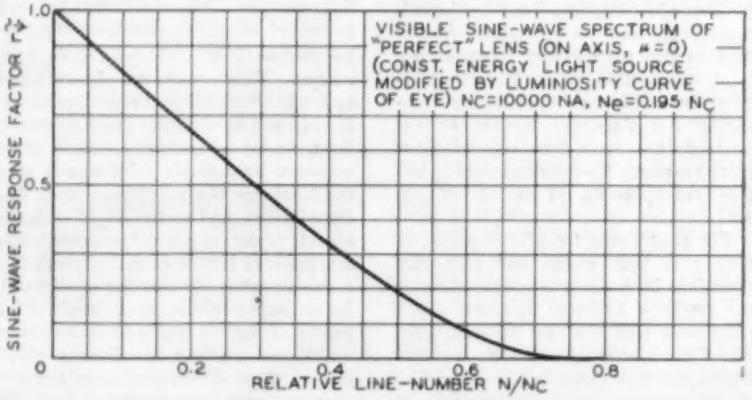
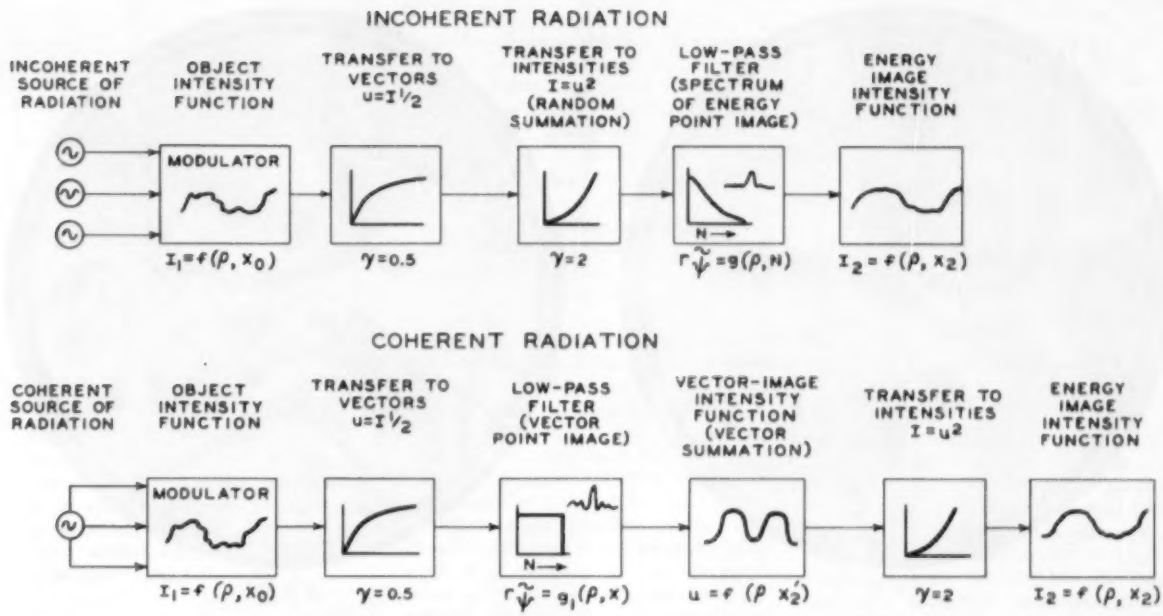

VISIBLE SINE-WAVE SPECTRUM OF "PERFECT" LENS (ON AXIS, μ = 0) (CONST. ENERGY LIGHT SOURCE MODIFIED BY LUMINOSITY CURVE OF EYE) NC = 10000 NA, Ne = 0.195 NC
SINE-WAVE RESPONSE FACTOR r↓
1.0
0.5
0
0.2
0.4
0.6
0.8
1
RELATIVE LINE-NUMBER N/NC

Fig. 141. Sine-wave spectrum of "perfect" lens, for visible light, $\mu = 0°$.



142a. Block diagram of imaging processes by a lens for coherent and incoherent light.

minated with parallel cophasal light. All object points are now synchronous cophasal oscillators. Their spherical radiation is converted by aberration-free front lens elements into plane-waves at the lens aperture in which every point is again considered as a point source of spherical waves as discussed in the preceding section. The aberration-free lens elements following the aperture focus the parallel ray beams from each object point at corresponding points on the image plane, forming vector point-images (curve *U* in Fig. 137). Because the phase of the resultant vector of parallel ray beams originating at different object points, but reaching the same image point, is identical (for a "perfect" lens), the total amplitude at an image point is obtained by a direct addition of vector amplitudes (instead of their squared values). Image-intensity functions are hence computed by taking first the square root of the object intensity-function to obtain the object vector function. This function is modified by the aperture process of the *vector point-image*, furnishing the vector-image function which is finally squared to obtain the image-intensity function. The difference between incoherent and coherent illumination is represented by the block-diagrams, Fig. 142a, where the square root and squaring operations are assigned to $\frac{1}{2}$-power and square-law transfer-characteristics in appropriate sequence with a low-pass filter representing the aperture process. The sine-wave spectrum of the filter for incoherent illumination is the transform of the *energy point-image*. (Compare #4 of Fig. 120.) For coherent illumination, the passband of the filter is the sine-wave spectrum of the *vector point-image*. (Compare #2 of Fig. 120.) Because the latter is the transform of the lens aperture, the spectrum of the vector point-image is directly the transmittance along a radius of the lens aperture. The sine-wave spectrum of a "perfect" lens used with coherent monochromatic illumination has therefore a rectangular shape with an abrupt cutoff at N_c for *all* lens stops having uniform transmittance ($\tau = 1$) and diametric symmetry (circle, rectangular, parallelogram, etc.)

$$r_{\tilde{\psi}} = 1, \qquad N < N_c$$
$$r_{\tilde{\psi}} = 0, \qquad N > N_c \qquad (132)$$

Because the aperture diameter is the inverse transform of the point image, the cutoff resolution (see broken line curve in Fig. 138) for axial coherent illumination is one-half that for incoherent light:

$$N_c = 2000\ N.A./\lambda \qquad (133)$$

for f: $\geqq f{:}2$,

$$N_c = 1000/\lambda f{:}$$

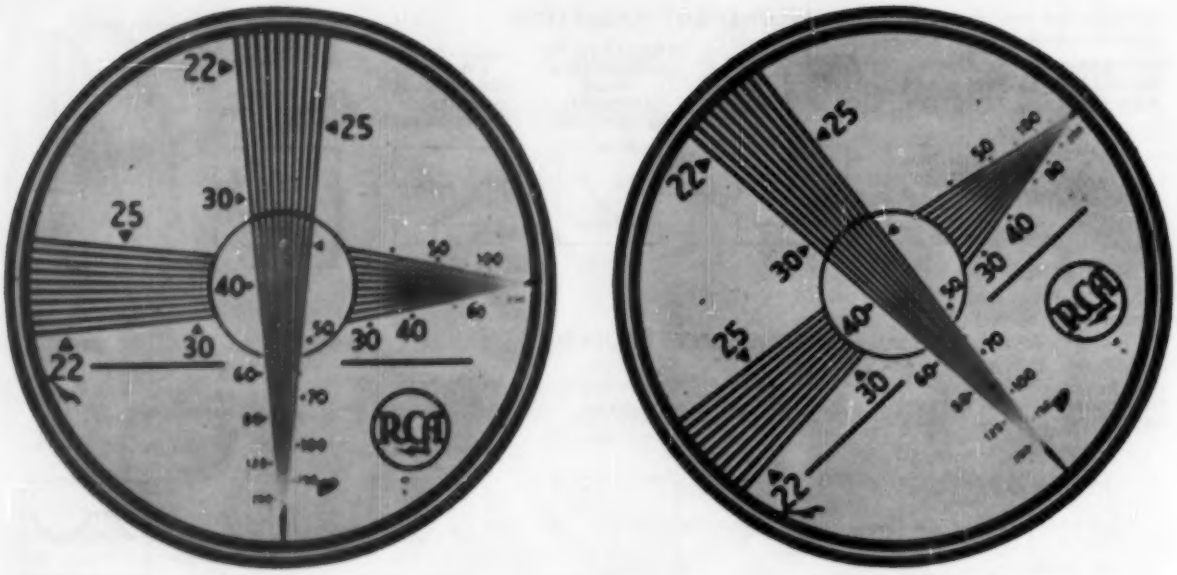
The differences in resolving power (N_c) and amplitude response for coherent and incoherent illumination are illustrated by the photographs Fig. 142b and 142c respectively, taken with a 42-mm objective having a square stop of 2-mm side length. The line-number scale of the patterns is to be multiplied by 2.5 to obtain television lines per millimeter. Note the increased resolution of the square lens aperture in the diagonal direction (Fig. 142b) when the pattern is turned 45°; and also the increase in resolution and loss of amplitude with incoherent illumination in Fig. 142*c*.

It is obvious from Fig. 142a that coherent illumination causes distortion of image intensity functions for large "modulation" percentages of the object illumination i.e. for high contrast objects. The distortion decreases with decreasing contrast because small sections of the two transfer characteristics are substantially linear.

(c) *Edge Transition (Monochromatic Light)*

The edge transition of the "perfect" lens is obtained according to Eq. (104) by integrating its line transmittance (Fig. 139), which can be obtained by a harmonic synthesis from its sine-wave spectrum (Fig. 138).

The edge transition ΔI_2 obtained with *incoherent* monochromatic light is shown in Fig. 143. For coherent illumination, the line transmittance of the vector point image (curve *U* in Fig. 137) is a $(\sin x)/x$ function for all directions. According to the diagram, Fig. 142a, edge transitions are obtained by first taking the square root of the object step function $I_1 + \Delta I_1$ to obtain the object vector step function $U_1 + \Delta U_1$, which depends numerically on the steady level I_1. When, for example, $I_1 = \Delta I_1 = 0.5$ the corresponding vectors are $U_1 = \sqrt{0.5}$ and $\Delta U_1 = 1 - \sqrt{0.5}$. The vector image is obtained by scanning the step with the $(\sin x)/x$ line transmittance of the vector point image (see Eq. (104)) and has the form $\Delta U_2 = \frac{1}{K}\int \frac{\sin x}{x}\, dx$. Before squaring to obtain the intensity function, the steady value U_2 must be added to ΔU_2. The results obtained for $I_1 = 0$, $\Delta I_1 = 0.5$ and $I_1 = 0.5$, $\Delta I_1 = 0.5$ are shown in Fig. 144 and demonstrate the distortion



$\rho = 0$ $\rho = 45°$

Fig. 142b. Test pattern images formed with coherent light by a 42 mm lens with square stop of 2 mm side length for pattern orientation $\rho = 0°$ and $\rho = 45°$.

of symmetry caused by the squaring operation for a high-contrast step (100 per cent for $I_1 = 0$) in comparison with a 50 per cent contrast step, as stated in the preceding section. The examples demonstrate also in general the effect of operating bias (I_1) and nonlinear transfer characteristics ($\gamma_1 = 0.5$ and $\gamma_2 = 2$, see Fig. 142a) on the waveform distortion.

(d) Equivalent Passbands (N_e) for Incoherent Light

Integration of the squared sine-wave spectra (Figs. 138, 140 and 141) furnishes the equivalent passbands for circular lens stops, τ = const. and $\mu = 0$:

$$\left.\begin{aligned} N_{e(0)} &= 0.271\ N_o \text{ (monochromatic)} \\ N_{e(0)} &= 0.213 N_o \text{ (“white,” const. energy, 0.4–0.7 } \mu\text{)} \\ N_{e(0)} &= 0.195 N_o \text{ (“luminosity” spectrum)} \end{aligned}\right\} \quad (134)$$

For off-axis positions, the "perfect" lens has an elliptical point-image with major and minor axes in the radial and tangential directions. The corresponding N_e values are

$$\left.\begin{aligned} N_{e(r)} &= N_{e(0)} \cos^3 \mu \\ N_{e(t)} &= N_{e(0)} \cos \mu \end{aligned}\right\} \quad (135)$$

The symmetric equivalent $\overline{N}_e$ obtained with Eq. (121) is hence

$$\overline{N}_e = N_{e(0)} \cos^2 \mu \quad (136)$$

With respect to the f: number or numerical aperture ($N.A.$) of the lens, Eq. (131) furnishes the following relations for monochromatic light:

$$N^{\circ}_{e(0)} = 542/N.A., \quad \text{or} \quad N_{e(0)} = 1084\ N.A./\lambda \quad (137)$$

For "white" light having a constant energy spectrum between $\lambda = 0.4\ \mu$ and $\lambda = 0.7\ \mu$ and for light having a luminosity weighting, the equivalent passbands for $\mu = 0$ are closely:

$$\left.\begin{aligned} N^{\circ}_{e(0)} &\simeq 1065/f:, \quad \text{or} \\ N_{e(0)} &= 2000\ N.A. \text{ (white)} \\ N^{\circ}_{e(0)} &\simeq 975/f:, \quad \text{or} \\ N_{e(0)} &\simeq 1830\ N.A. \text{ (luminosity)} \end{aligned}\right\} \quad (138)$$

Off-axis conditions are obtained with Eqs. (135) and (136). The units in these expressions are: N_e in (television) lines/

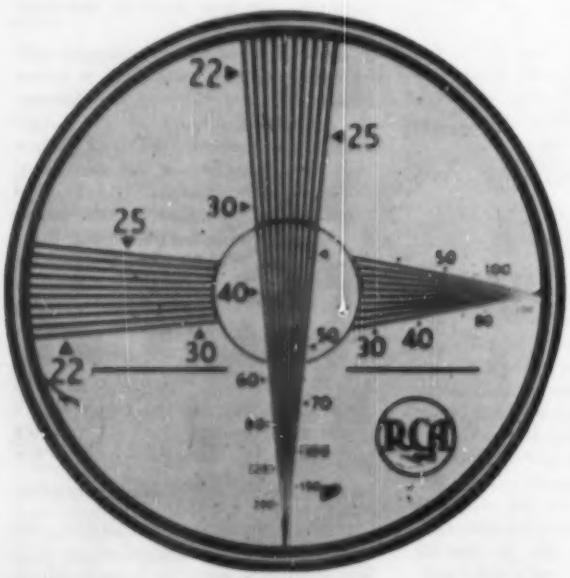


Fig. 142c. Test pattern image formed with incoherent light by the same lens used for Fig. 142b.

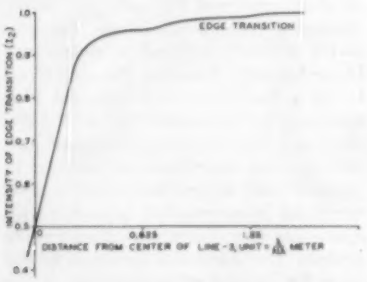


Fig. 143. Edge transition of "perfect" lens, monochromatic light, incoherent illumination.

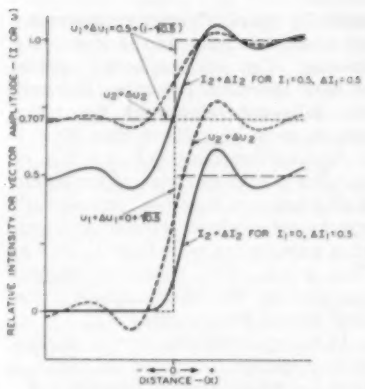


Fig. 144. Vector and intensity functions of edge transitions obtained with monochromatic light and coherent illumination, showing the distortion of step-function signal ΔI_2 caused by squaring the vector function $U_2 + \Delta u_2$ when the "modulation" is high ($I_1 = 0$).

mm, λ in microns. The asterisks indicate values limited to $f: \geq f{:}2$.

(ε) Characteristics of Practical ("Imperfect") Lenses

The performance of a "perfect" optical or electrical lens is seldom realized in practical instruments of larger aperture, because it is difficult to maintain an undistorted wave front within fractions of a wavelength for large solid angles, an extended field, and over the frequency range of the radiation. The sine-wave spectrum of the imperfect practical device is the product of its theoretical diffraction spectrum ($\bar{r}_d(N)$) caused by its boundaries (lens stop) and an aberration characteristic $\bar{r}_a(N)$, which takes the place of the "flat" amplitude spectrum of the perfectly corrected instrument as illustrated by Fig. 145. *The aberration spectrum* $\bar{r}_a(N) = g(\rho,N)$ is hence a measure of the degree of correction achieved in the instrument. It is obtained by dividing the sine-wave spectrum $r_g(N)$ of the instrument by its theoretical diffraction spectrum:

$$\bar{r}_a(N) = r_g(N)/\bar{r}_d(N) \qquad (139)$$

The direct calculation of wave-front distortion and aberration factors is rather involved and beyond the scope of this paper. The measurement of sine-wave spectra of practical devices, however, is comparatively simple and furnishes all the information required for an accurate system evaluation.

2. Photographic Systems

The elements of conventional photographic systems are lenses, photosensitive grain structures, and viewing screens, which can be described in the space domain or by their sine-wave spectra. Given their sine-wave spectra, their combination by multiplication is straightforward and is illustrated by examples given in Table IX, Part II, p. 208.

It has been pointed out (Part II, pages 188–191) that photographic film is not a single aperture process, because the optical properties of its crystal structure during exposure are quite different from those of its grain structure after development. The degree of development is not necessarily uniform and grain sizes can vary as a function of exposure and density distribution.

The diffusion and diffraction of light by grain layers is a function of density, distances, wavelength and coherence of the printer or projection light. The overall sine-wave image spectrum of an exposed and developed photographic emulsion depends, therefore, on many parameters which must be closely controlled to obtain consistent results. Even then the spectrum is not perfectly independent of exposure because the spectrum of the developed grain structure (second aperture effect) decreases with density as illustrated by Fig. 146. The spectra shown in this illustration were obtained by projecting constant-amplitude sine-wave patterns on uniformly exposed film, and measuring the amplitude of the diffused image. Aperture variations are not unique to film; they occur in lenses and in television camera tubes and kinescopes, where both electronic and optical effects cause spot sizes and spectra to vary as functions of intensity and intensity distribution in the object. In good designs these variations are reduced to acceptable values which can be specified, if necessary, by a family of spectra or N_r-values against representative parameters.

Data on the sine-wave image spectrum of photographic emulsions (not to be confused with their "noise" spectrum) are to this date unavailable from film manufacturers. Measurements made by the author in 1948[2] on commercial film types such as plus X, super XX, microfilm and Kodachrome at various exposure levels, as well as measurements on a number of phosphor grain structures for kinescopes, confirmed that their point image is determined substantially by an exponential law of light diffusion ($\tau = \varepsilon^{-r/r_0}$) as discussed in connection with Fig. 46a and b, Part II, p. 190. A reference to published film ratings could be established only through the resolving power (N_{∞}), which was found to be the line-number giving a 2% sine-wave response. "For want of a better value" this relation was used to refer the specific line-number scales of the measured films to the general diffusion characteristic representing normal grain structures (Fig. 46a, Part II, or Fig. 125). This correlation does not exist when the point-image transmittance of the grain structure does not obey the diffusion law, or when selective effects occur in the development. The sine-wave spectrum of other film types should therefore be investigated by measurement. A similar comment must be made regarding lens performance. The actual sine-wave spectra of practical lenses depart so much from those of the "perfect" lens, that one must rely entirely on measurements. It is hoped that both film and lens manufacturers will eventually supply this information together with other data, to facilitate evaluation of systems using lenses and image storage in photographic emulsions.

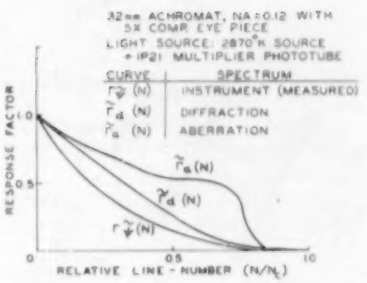


Fig. 145. Sine-wave spectrum and aberration spectrum of an "imperfect" lens.

Numerical values (measured) for a number of photographic processes will be given in a later section.

3. Television Systems

Point-Images Impulse-Functions and Sine-Wave Spectra

The point-image of an electrical circuit or system is its response to a "unit impulse" of infinitesimal duration. The impulse or time-function $I = f(t)$ of electrical circuit elements are their "aperture"-functions, and can be combined by convolution (cascading) as discussed in Section A, 3. The time t corresponds to the displacement x in the

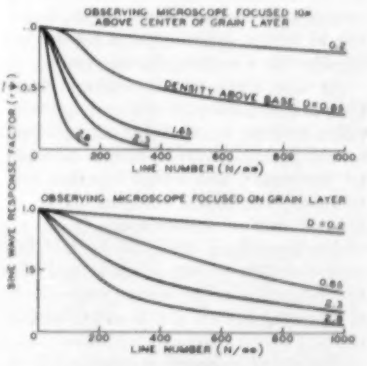

OBSERVING MICROSCOPE FOCUSED ON ABOVE CENTER OF GRAIN LAYER
DENSITY ABOVE BASE D=0.85
OBSERVING MICROSCOPE FOCUSED ON GRAIN LAYER
SINE WAVE RESPONSE FACTOR (r)
LINE NUMBER (N/∞)

Fig. 146. Spectra of diffusion caused by the grain structure of developed super xx film upon illumination with directed light (second aperture effect) for an out-of-focus condition (contact printing) and an in-focus condition (projection printing).

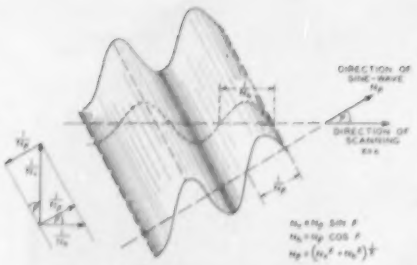


Fig. 147a. Horizontal and vertical components of a sine-wave pattern forming an angle ρ with the direction of scanning.

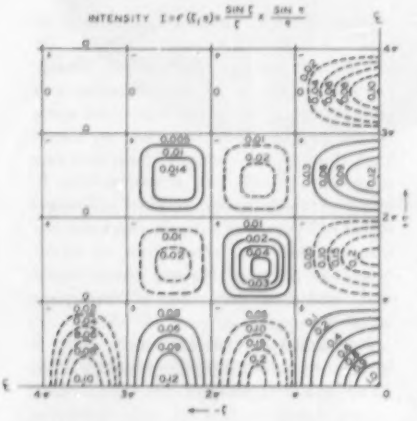


Fig. 147b. Topographic representation of point-image transmittance $\tau = f(\zeta, \eta)$ of the "perfect" television system for $N_c(h) = n_r$.

scanning direction. Because electrical circuits have one dimension only, the impulse function is single-valued in a linear system and is, therefore, the line-transmittance of the circuit. $I = f(t) = F(t)$ (Figs. 88 and 93 of Part III). The impulse-function and its transform, the "frequency" spectrum $r\vec{e},\theta = g(\omega) = g(\rho,N)$ are hence directly reversible. A rectangular impulse, for example, has a $(\sin x)/x$ type spectrum, and a $(\sin x)/x$ impulse has a rectangular spectrum.

An area, i.e. a two-dimensional function, is transmitted in conventional television systems by scanning along close-spaced parallel paths forming a horizontal line-raster. The image function has, therefore, horizontal components ($x = h$) and vertical components ($y = v$), which have been modified by the impulse-function of the circuits and the raster-function of the system respectively as discussed in Part III, B and C, of this paper.

The optical sine-wave spectrum $r_{\vec{e}}(\rho) = g(\rho,N)$ of a television image is determined in general by the scanning method which is specified for line rasters by the pitch distance or its reciprocal, the raster constant (n_r), the sine-wave spectra $r_{\vec{e}(a)}$ and $r_{\vec{e}(b)}$ of the two-dimensional analyzing and synthesizing apertures δ_a and δ_b preceding and following the raster process, and by the sine-wave line-number spectrum of the electrical system. Because of the fixed scanning direction (horizontal), an optical sine-wave pattern oriented at an angle ρ with respect to the scanning direction (see Fig. 147a) and having a line-number $N_{(\rho)}$, can be split into vertical and horizontal components having the line numbers

$$N_v = N_{(\rho)} \sin \rho$$
$$\text{and} \qquad (140)$$
$$N_h = N_{(\rho)} \cos \rho$$

It is obvious that rotation of a pattern $N_{(\rho)}$ from $\rho = 0°$ to $\rho = 90°$ causes N_h and the corresponding electrical frequency $f_{(h)}$ (see Eq. (61)) to change from a maximum to zero, while the component N_v increases from zero to the maximum $N_v = N_{(\rho)}$ at $\rho = 90°$. *The sine-wave spectrum of the electrical system*, therefore, *modifies the spectrum of the television image in all directions*, and its effect is a maximum in the horizontal direction ($\rho = 0$), and zero in the vertical direction ($\rho = 90°$).

Continuity Requirements and Restrictions of the Vertical Aperture-Spectrum

It will be assumed that the value of frame frequency, phosphor decay time, luminance level and interlacing (if used) have been chosen such, that the sequential generation of the retinal image occurs within the storage time of the visual process, in order that it may be regarded equivalent to a simultaneous presentation of one frame. The two-dimensional aperture process δ_h (kinescope and eye) following the raster process has to perform the function of establishing continuity in the vertical direction of the retinal image. Its resolving power $N_{c(h)}$ must, therefore, be limited to the value $N_{c(h)} \leqq 2\,n_r$ to eliminate the carrier-frequencies n_r and integral multiples of the raster "pulse-wave," which otherwise would cause a disturbing line-structure (flat field condition stated by Eq. (56a) Part III).

A mathematically complete elimination of all spurious modulation components (sidebands, beats) requires that the resolving power $N_{c(a)}$ and $N_{c(b)}$ of both aperture processes, preceding and following the raster process, be restricted to one-half the value producing a "flat" field, i.e.: $N_{c(h)} = N_{c(a)} \leqq n_r$, as illustrated by the raster characteristic, Fig. 70 of Part III.*

The "Perfect" Television System

The line-transmittances of the mathematically "perfect" scanning apertures are readily determined in the frequency domain. *The vertical sine-wave spectrum* of both apertures, preceding (camera) and following (kinescope) the raster process, must be uniform from $N = 0$ to the cutoff line-numbers $N_{c(a)} = N_{c(b)} = n_r$. The overall spectrum of the system is the product of these two "rectangular" spectra and an identical spectrum of constant response ($r_{\vec{e}} = 1$) from $N_v = 0$ to $N_{c(v)} = n_r$. The equivalent vertical passband of the mathematically "perfect" system has the value $N_{c(T)v} = n_r$.

In the space domain, rectangular frequency spectra correspond to $(\sin x)/x$ type line-transmittances (impulse functions) which have a length s_v between 1st zero points equal to $s_v = 2x_0 = 2/N_c$ (compare Fig. 88, Part III). Because of the restriction $N_{c(a)} = N_{c(b)} = n_r$, the length s_v of the two $(\sin x)/x$ type apertures is equal to twice the raster pitch distance:

$$s_v = 2/n_r \qquad (141)$$

In the horizontal direction a line-raster provides continuity along the scanning lines. The spectrum of the mathematically "perfect" television system should be "flat" and limited by a sharp electrical cutoff. An electrical filter having a rectangular passband has a $(\sin x)/x$ line-transmittance, which has a length $s_h = 2/N_{c(h)}$. The scanning apertures must therefore have either an infinitesimal width in the scanning direction or a $(\sin x)/x$ line-transmittance, identical to or of smaller width than that of the electrical filter. It follows that *the scanning apertures of the mathematically "perfect" television system have a* $(\sin x)/x$ *line-transmittance in both directions with lengths* $s_v = 2/n_r$ *and* $s_h \leqq 2/N_{c(h)}$ *between first zero points.* The aperture of the entire system is identical with either scanning aperture, because any number of identical $(\sin x)/x$ apertures can be cascaded without degradation of their spectrum. The transmittance $\tau = f(\zeta,\eta)$ of the two-dimensional aperture is shown in Fig. 147b. It is calculated as the product of two crossed line-images having $(\sin x)/x$ type cross sections. The three-dimensional spectrum representation of this aperture is a rectangular solid with side lengths (double spectrum lengths) $2N_{c(h)}$ and $2n_r$ respectively and a diagonal $2N_{c(d)} = 2(N_{c(h)}^2 + n_r^2)^{\frac{1}{2}}$. The equivalent passbands of the perfect system having rectangular frequency spectra are, therefore:

$$N_{e(T)v} = n_r,\ N_{e(T)h} = N_{c(h)}$$
$$\text{and the rms value (Eq. 122) is} \qquad (142)$$
$$\overline{N}_{e(T)} = \left(\frac{4}{\pi}\, n_r N_{c(h)}\right)^{\frac{1}{2}}$$

The image transmitted by this system is similar to that obtained with a "perfect" optical system having a rectangular lens stop and used with *coherent* monochro-

* This requirement is well known from carrier modulation theory, which states that a modulation spectrum limited in frequency by a filter (a) to one-half the carrier frequency can be recovered without distortion when the demodulated output is limited by a filter (b) to one-half the carrier frequency.

matic light (compare Fig. 142b, also 85a and 85b, Part III). The image has identical resolution and edge transients, of 13.8% peak-to-peak amplitude in both horizontal and vertical directions when $n_r = N_{e(b)}$. Its resolution increases by $\sqrt{2}$ for $\rho = 45°$ as shown in Fig. 142b. The transient amplitudes can be adjusted to lower values by modification of aperture shape and cutoff sharpness in the desired direction, as shown in Figs. 86 to 89 of Part III. Gradual cutoff characteristics beginning near $N = 0$, such as shown in Fig. 86a or 87a, give a better shaped and less visible transient than partially flat characteristics having equal equivalent passbands and a steeper sinusoidal cutoff. Aside from the variation of transient visibility (see below), the performance of the mathematically "perfect" system is independent of the viewing distance.

It is worth mentioning that a point-raster process (similar to a printing process) employing apertures with $(\sin x)/x$ type line-transmittances in both x and y directions, will provide an identical structure-free image, which can be transmitted as a series of independent scalar quantities equal in number to the total number of raster points in the frame area.

"Imperfect" Practical Systems

The line-transmittance and sine-wave spectrum of actual scanning apertures (camera tubes, kinescopes) are represented closely by error functions (compare Part III, Figs. 94 to 97). The limit of resolution (N_e) is approached asymptotically. Because of excessive loss of amplitude response it is impractical to eliminate spurious signals completely in the vertical direction by letting $N_{e(a)} = n_r$. "Vertical" aperture correction processes which can construct the $(\sin x)/x$ apertures of the perfect system from degraded apertures are not in use at this time. It is, therefore, of interest to examine the practical condition of a gradual and imperfect cutoff at $N = n_r$, which is used to gain normal aperture response at the expense of some spurious response.

When both $N_{e(a)}$ and $N_{e(b)}$ are made smaller than $2n_r$, the spurious response consists of difference line-numbers: $N_D = 2n_r - N$, or in relative units $N_D/n_r = 2 - (N/n_r)$. This condition is obtained with error curve spectra when their equivalent passband is smaller than $0.67\ n_r$ as shown in Fig. 148*. The normal fundamental response of the system in the vertical direction is the product

$$r_{\bar{g}(v)} = r_{\bar{g}(a)N}\, r_{\bar{g}(b)N} = f(N) \qquad (143)$$

The spurious response for the difference line-number is

$$r'_{\bar{g}(v)} = r_{\bar{g}(a)N}\, r_{\bar{g}(b')D} = f(N, N_D) \qquad (144)$$

* The spurious response, $r_{\bar{g}(b')D}$, shown in Fig. 148 is obtained with constant input signals.

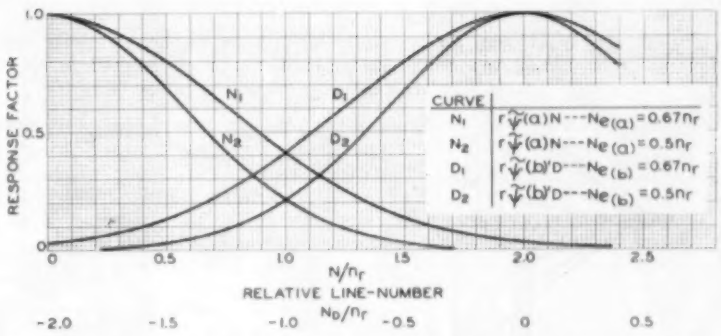


Fig. 148. Sine-wave spectra (N_1 and N_2) of scanning apertures giving essentially flat fields and a spurious response (D_1 and D_2) due to the raster process.

A graphic representation of Eq. (144) is shown by Fig. 149. Inspection of Fig. 149 shows that equal values $N_{e(a)} = N_{e(b)}$ give a maximum spurious response $r'_{\bar{g}(v)} = r_{\bar{g}(a)}^2$ at $N = N_D = n_r$, while unequal values $N_{e(b)} \neq N_{e(a)}$ shift the maximum. It is seen further that the product of the curves $N_1 D_2$ becomes zero at low line-numbers when $N_{e(b)} < N_{e(a)}$, which is preferable to $N_{e(b)} > N_{e(a)}$ (high frequency interference is less visible), although the fundamental response may be identical.

The condition $N_{e(b)} < N_{e(a)}$ is obtained naturally in practical cases, because the spectrum $r_{\bar{g}(b)} = g(N)$, is the product of the spectra of kinescope and the visual process, and is decreased by increasing the viewing distance (see Eq. (87) Part III). Numerical system evaluations including other directions (see below) lead to the conclusion that the spurious response is reduced to acceptable levels when the *vertical* aperture passbands have the values

$$N_{e(a)v} \approx 0.67 n_r, \qquad N_{e(b)v} \leqq 0.5 n_r \quad (145)$$

The Sine-Wave Spectra $r_{\bar{g}(\rho)}$ of the System

The sine-wave response in the scanning direction $\rho = 0°$ (horizontal) is the product of the two-dimensional aperture response $r_{\bar{g}h}$ and the electrical response $r_{\bar{e}}$ as discussed in Part III, Eq. (65):

$$r_{\bar{g}(a)h} = (r_{\bar{g}}\, r_{\bar{e}})_{(N/N_e)h} \qquad (65)$$

The horizontal spectrum has been computed for a variety of system element combinations and plotted in the form of generalized characteristics in Figs. 86 to 87 of Part III.

The spectrum in any specified direction ($\rho \geqq 0°$) is the product of the aperture spectra and the electrical spectrum components in the direction ρ, for which the line-number N_ρ of the electrical spectrum is stretched by the factor $1/\cos\rho$ as stated by Eq. (140) and illustrated in Fig. 150 for a particular case. The system response is expressed by the general relation

$$r_{\bar{g}(a)\rho} = r_{\bar{g}(a)\rho}\, r_{\bar{g}(b)\rho}\, r_{\bar{e}\rho} = g(N,\rho) \qquad (146)$$

where the index ρ indicates the direction in which the response or line-number is to be taken and the line-number for the electrical response r_e is computed with

$$\left.\begin{aligned} N_\rho &= N_h/\cos\rho \\ \text{or} \quad (N/N_e)_\rho &= (N/N_e)_h/\cos\rho \end{aligned}\right\} (147)$$

The effects of electrical bandwidth limitation and correction can now be computed as a function of direction. Assume that the apertures δ_a (camera tube with lens) and δ_b (kinescope + eye) have circular symmetry and, therefore, constant equivalent passbands $N_{e(a)\rho} = 0.67\ n_r$, $N_{e(b)\rho} = 0.5\ n_r$. Assume further that the horizontal resolution is limited by the electrical channel to $N_{e(b)} = 0.7\ n_r$ (standard U.S.A. television system where $n_r = 490$ and $N_{e(b)} = 340$ lines). By the use of electrical aperture correction (curve 1 in Fig. 150) the horizontal spectrum $r_{\bar{g}(a)} \cdot r_{e(b)}$ in the video channel (curve 6) can be given a flat response. Note that this spectrum does not yet contain the spectrum $r_{\bar{g}(b)}$ of the kinescope and eye. The electrical response $r_{\bar{e}(\rho)}$, computed as a function of ρ with Eq. (147), results in a family of characteristics shown by curves

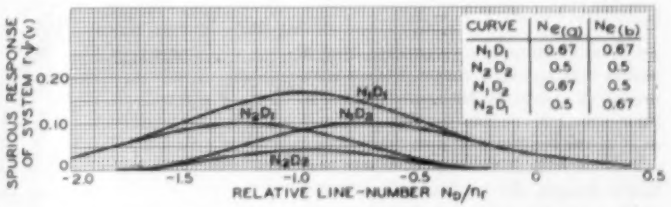


Fig. 149. Spurious response products resulting from the raster process and combinations of the aperture spectra shown in Fig. 148.

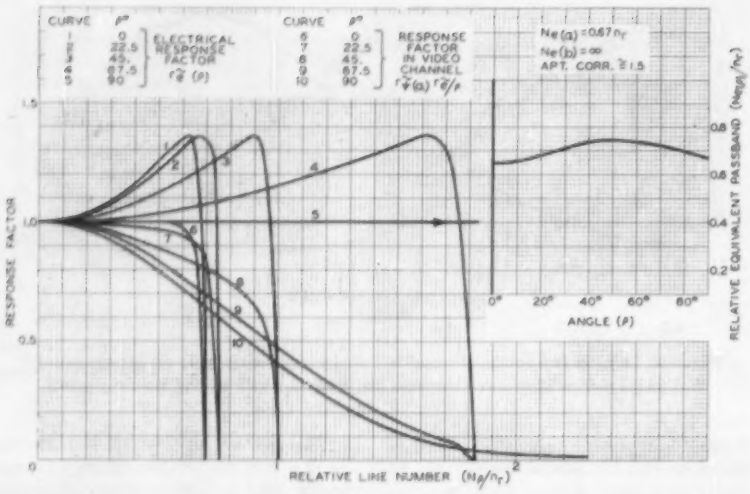


Fig. 150. Sine-wave spectra of aperture corrected video channel without (curves 1 to 5) and including (curves 6 to 10) the camera tube as a function of direction (ρ); and equivalent passbands $N_e(\rho)$ of curves 6 to 10.

1 to 5 in Fig. 150. The products $r_{\bar{\varphi}(a)}\, r_{\bar{e}(\rho)}$ furnish a second family of spectra shown by curves 6–10 in Fig. 150. It is seen that the resolving power increases gradually from $N_e = N_{e(\delta)}$ for $\rho = 0°$ to the resolving power of the aperture δ_a at $\rho = 90°$. The equivalent passband $N_{e(\rho)}$, however, remains substantially constant as shown by the insert in Fig. 150. Inclusion of the spectrum $r_{\bar{\varphi}(\delta)}$ furnishes the system response (Eq. (146)) which is shown in Fig. 151. The differences in curve shape and resolving power have been reduced by the addition of δ_b and the equivalent passbands are lower, but have become relatively higher for $\rho = 0°$.

It has been demonstrated so far that a good balance of the equivalent passbands $N_{e(\delta)\rho}$ is obtained in television systems with horizontal aperture correction and apertures specified by Eq. (145), when the resolution of the video channel has the value:

$$N_{e(\delta)} = 0.7 n_r \qquad (148)$$

Substitution of this equation into Eq. (63) furnishes preferred constants for the design of television systems employing optimum horizontal aperture correction (flat response in the video channel).

$$\left.\begin{array}{l}\text{Raster line-number: } n_r \cong \\ \quad 1.3(\Delta f/T_f)^{\frac{1}{2}} \\ \text{Scanning line-number: } n_s \cong \\ \quad 1.4(\Delta f/T_f)^{\frac{1}{2}} \\ \text{Horizontal Cutoff: } N_{e(\delta)} = 0.7 n_r\end{array}\right\} (149)$$

To obtain optimum performance from a system containing a raster process with imperfect apertures, *the aperture process of the eye must be included* in the passband $N_{e(\delta)}$ of the synthesizing aperture.

For very short viewing distances and larger images, the passband $N_{e(\delta)}$ is not limited by the eye, and the kinescope must then be given an equivalent passband $N_{e(\delta)} = N_{e(\delta)}$. For increased viewing distances, however, the eye itself can perform the functions of the synthesizing aperture δ_b because $N_{e(eye)} \leqq N_{e(\delta)}$. It is obvious that the equivalent passband $N_{e(\delta)}$ required for the kinescope may vary theoretically from $N_{e(\delta)} = N_{e(\delta)}$ to $N_{e(\delta)} = \infty$ as a function of viewing distance, and that *the optimum equivalent passband $N_{e(T)}$ of the "imperfect" practical television system itself does depend on the viewing distance for which the system is to be designed.*

Edge Transients: The sine-wave spectrum of the *retinal image* should have a gradual cutoff to prevent disturbing edge transients. A reexamination of design values is therefore indicated. It has been shown in Part III, Fig. 89, that the peak-to-peak transient ripple is a function of the relative equivalent passband $\alpha = (N_e/N_c)_k = (N_e/N_c)\rho$. Thet ransient ripple obtained for the preceding example is shown in the insert of Fig. 151 as a function of ρ. A ripple greater than 2%* of the step amplitude is objectionable in the retinal image, particularly in the darker and medium levels of the tone scale. A 2% peak-to-peak ripple caused by a luminance step $\Delta B = B_2 - B_1 = 1–0.1$, for example, has the value $0.02\ \Delta B = 0.018$ which, in a linear system is represented by the deviations $\sigma_2 = 0.018$ at the level B_2 and $\sigma_1 = 0.18$ at the level B_1. In actual nonlinear systems, these percentages are modified (similarly to "noise"-values), by the point gamma of the system (including the eye), which in general decreases with B (toe) and, therefore, reduces σ_1 to a much lower value.

The previously assumed aperture passband $N_{e(\delta)} = 0.5\ n_r$ must, therefore, be reduced to decrease the ripple to 2% at $\rho = 0°$ which, according to observations, appears to be a satisfactory value. It follows from Fig. 89b, Part III, that this requires $N_{e(\delta)} = 0.45\ N_{c(\delta)}$ for the U.S.A. standard $N_{c(\delta)} = 340$. In terms of the raster constant $N_{c(\delta)} = 0.7\ n_r$, one obtains $N_{e(\delta)} \leqq 0.32\ n_r$ for $\rho = 0$. Because the equivalent passband $N_{e(\delta)}$ is the cascaded value of $N_{e(a)}$ and $N_{e(b)}$, and $N_{e(a)}$ has been given the value $N_{e(a)} = 0.67\ n_r$, the value $N_{e(b)}$ can be computed with Eq. (125b):

$$N_{e(b)} \leqq 0.36 n_r \text{ for } N_{e(a)} = 0.67 n_r \qquad (150)$$

The constants for optimum performance of a standard U.S.A. television system are summarized by Eqs. (149) and (150).

The equivalent passband $N_{e(T)}$ of the television system itself can be computed for specified viewing distances (d/V) and raster constants. The equivalent passband of the kinescope ($N_{e(b)}$) is first computed with Eqs. (87) and (125b) for the raster constant n_r, for example the U.S.A. standard $n_r = 490$ lines, as

* It is pointed out that the transient ripple in the video channel, ahead of the apertures of kinescope and eye, is very much larger because of the high α value at that point.

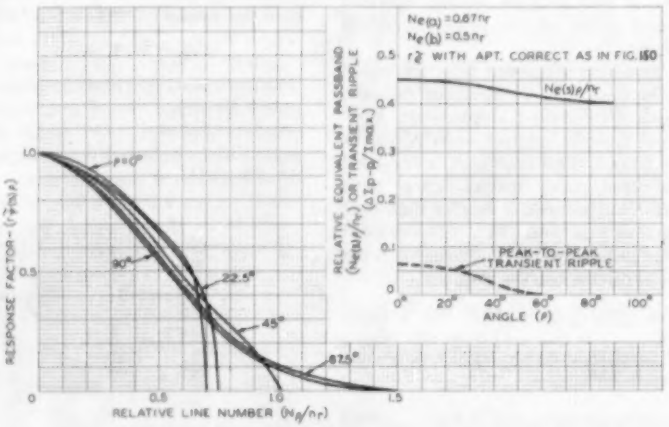


Fig. 151. Overall spectra and equivalent passbands of a practical "imperfect" television system approaching optimum design.

shown in columns 1 to 3 of Table XXVI. The optimum aperture correction compensates the decreasing camera response $r_{g(a)}$ so that the response in the video channel is equal to the flat spectrum $r_{\bar{g}(f)}$ of the electrical sharp cut-off filter (curve ∞ in Fig. 86a, Part III, shown as curve 6 in Fig. 150). The relative bandwidth (α) of the system can hence be obtained from Fig. 99a, curve 1, letting $(N_{e(\bar{g})}/N_e)_h = N_{e(k)}/N_{e(h)}$ as listed in columns 4, 5, and 6. The corresponding numerical values $N_{e(\bar{g})h}$ are tabulated in column 7. The equivalent vertical passband $N_{e(\bar{g})v}$ is computed by cascading the values $N_{e(k)}$ and $N_{e(a)}$ (column 8). The equivalent passband $\bar{N}_{e(\bar{g})}$ (column 9) of the television system is finally obtained with Eq. (121).

The last column of Table XXVI shows the equivalent passband $\bar{N}_{e(a)}$ of the retinal image computed by cascading $N_{e(eye)}$ with $N_{e(\bar{g})}$. In accordance with the design procedure, the value $\bar{N}_{e(a)}$ is constant for all viewing distances for which the eye has a value $N_{e(eye)} > 0.36\ n_r$. For comparison, a standard 35mm motion-picture process has the value $N_{e(M)} \simeq 250$ (see Table IX, 1 to 4, in Part II) and produces a retinal image at a viewing ratio of $d/V = 3.5$ having an equivalent passband $\bar{N}_{e(a)} \leqq 163$, which can be equaled with a practical standard U.S.A. television system of optimum design.

Equality of equivalent passbands in general does not require that the point-images or spectra of two images be alike. In this respect the *external* images on the television or motion-picture screen differ considerably. The design of the television system, however, is directed toward obtaining a *normal optical image at the retina* at a specified viewing distance. For the optimum design the retinal television image has no structure, and the shape of its spectrum equals substantially that of the retinal motion-picture image, the spectrum cutoff becoming somewhat sharper in the directions $\rho = 0°$ to 22°, but not to such an extent as to generate perceptible transients. (The reader may compare Fig. 151 which illustrates the uncorrected design having higher transient overshoots and sharper cutoff than obtained with the recommended values of Eq. (150).) Equality of equivalent passbands, particularly under these conditions, indicates an equality of subjective sharpness, which will be discussed in a later publication.

It is interesting that the performance difference between a well-designed practical system having an equivalent passband $\bar{N}_{e(\bar{g})} = 264$ for a 4:1 viewing distance and a mathematically perfect system ($\bar{N}_{e(\bar{g})} = 460$, Eq. (142)) is similar to that between an excellent practical lens system and the perfect lens.

The above design values are valid when the visual or recording process observing the television image is able to integrate the sequential presentation in the time of one picture frame into the equivalent of a simultaneous exposure. The preceding evaluation is based on the condition that one-dimensional horizontal aperture correction is used. It may be practical in the future to employ a two-dimensional correction by an electrical process which can produce a higher amplitude response with sharper cutoff in the vertical direction. It is obvious that this will result in different aperture specifications and a ratio $N_{e(k)}/n_r$ closer to unity.

Table XXVI. Equivalent Passbands N_e of 525-Line Television System With Δf = 4.25 Mc, $n_r = 490$, $N_{e(k)} = 340$, Optimum Practical Aperatures $N_{e(a)} = 0.67\ n_r = 328$, $N_{e(k)} = 0.36\ n_r = 176$, and Optimum Horizontal Aperture Correction.

(1) d/V	(2) $N_{e(eye)}$	(3) $N_{e(k)}$	(4) $N_{e(k)}/N_{e(h)}$	(5) α'	(6) α	(7) $N_{e(\bar{g})h}$	(8) $N_{e(\bar{g})v}$	(9) $\bar{N}_{e(\bar{g})}$	(10) $\bar{N}_{e(a)}$
3	250	250	0.736	0.81	0.66	194	199	197	163
4	188	500	1.47	0.93	0.865	255	274	264	163
5	150	∞	∞	0.975	0.95	279	328	302	142

Column Legends:

(1) Ratio of viewing distance to frame height.
(2) Equivalent passband of eye, Eq. (87), Part III, p. 153.
(3) Equivalent passband of kinescope.
(4) Relative equivalent passband of kinescope with respect to horizonta cutoff N_e.
(5) Square root of bandwidth factor from Fig. 99a, curve 1, Part III, p. 144, with $N_{e(\bar{g})} = N_{e(k)}$.
(6) Horizontal bandwidth factor.
(7) Equivalent horizontal passband of television system $= \alpha N_{e(k)}$.
(8) Equivalent vertical passband of television system ($N_{e(a)}$ and $N_{e(k)}$ in cascade).
(9) Equivalent passband of television system, Eq. (122).
(10) Equivalent passband of retinal image, computed with Eq. (121) for $N_{e(\bar{g})v} = (2)$, (3), and $N_{e(a)}$ in cascade; $N_{e(\bar{g})h} = \alpha N_{e(h)}$, with α from Fig. 99a, curve 1, Part III, for $N_{e(\bar{g})} = N_{e(eye)}$ in cascade with $N_{e(K)}$.

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Low-Power Telecasting

By M. E. WILLIAMSON
and STANLEY E. RODBY

Discussed are problems and procedures encountered in establishing low-power telecasting by the Armed Forces for the information and education of service personnel in isolated areas of the United States and in overseas areas where English language television is not available. Described are the development of Armed Forces Television, its "package" equipment, programming, personnel and costs of installation.

THE ARMED FORCES have amply demonstrated that adequate television service can be provided to small communities using very low powers and antenna heights. CSL-TV, at Lajes Field, Azores, and Loring Air Force Base, Limestone, Maine, are two Air Force Bases that have constructed television stations operating with an effective radiated power of roughly 30 w. These compare not unfavorably with the nighttime coverage of the average 250-w local standard broadcast station and are clearly adequate for the average city below 50,000 population.

The station at Loring Air Force Base, constructed in December 1953, using RCA equipment and representing a total investment of under $70,000, provides service to the entire base area and to other military installations within a radius somewhat greater than five miles.

In October 1954, Dage Television Division of Thompson Products built CSL-TV at Lajes Field for a total equipment cost of less than $50,000, and the station has operated from five to seven hours daily since then without the appreciable loss of any program time. The antenna at this station is 20 ft above the transmitter building, giving it an average height of approximately 100 ft above the base area. CSL-TV provides a signal adequate for satisfactory reception on stock model receivers throughout the entire base which extends approximately eight miles from the transmitter to the shore line. The signal extends over the ocean and the ultimate limit of its usability has not yet been determined.

The Armed Services are interested in television as a tactical aid and training device as well as for spreading good morale among the men. Their problem was to get inexpensive equipment that would telecast a program-bearing signal to a practically circular area about five miles in diameter. The first test of the efficacy of low-power television was made at Loring Air Force Base, which is far from any commercially operated TV stations.

Presented on April 20, 1955, at the Society's Convention at Chicago by Lt-Col M. E. Williamson and Maj Stanley E. Rodby (who read the paper), Office of Armed Forces Information and Education, Dept. of Defense, Washington 25, D.C.
(This paper was received on April 14, 1955.)

It was assumed that programs would consist mainly of 16mm kinephoto recordings and films, with an occasional "live" pickup. To meet these needs RCA proposed three plans. The first was strictly a minimal operation using that company's ITV-5 industrial equipment. The second plan was essentially a closed circuit or wired-carrier type system without the wires. It provided a broadcast-quality vidicon chain of the type used in many commercial stations for film pickup. This system is composed of the same equipment as in the high-quality system that was finally installed except that a less expensive camera is used. The camera employed is the TK-7A broadcast vidicon camera chain which uses an industrial television camera converted to broadcast standards. The bandwidth of this camera chain is 5 mc as compared with the 8-mc capability of the equipment now in use.

The third plan, which was chosen, consists of a standard 16mm film projector (type TP-16E) which is focused on the photoconductive camera tube (6326) in the vidicon film camera chain. A sync generator furnishes standard RETMA synchronizing pulses to operate the camera chain, and the resultant video signal is fed into the transmitter. A standard control console with a master monitor permits complete control of the video signal.

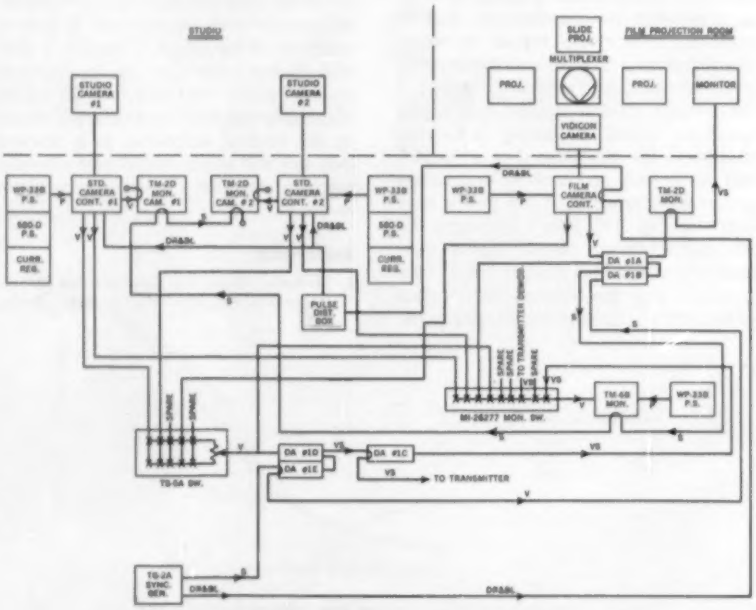
The vidicon camera is provided with a special mounting which permits an operator to aim the camera into the film projector or at a small "live" set.

The sound is fed either from the film projector or a microphone into the program amplifier and then into the sound transmitter. This system provides commercial studio grade equipment with an 8-mc bandwidth.

For live program operations, RCA modified the front camera plate to receive a standard lens, and supplied a Wollensak 2-in. lens with the equipment. The vidicon camera is a small, lightweight unit built around the RCA vidicon tube, 6326, and requires an incident light level of 100 ft-c for an acceptable TV picture. For scenes with considerable movement, however, up to 200 to 250 ft-c are recommended.

The camera is designed to use a single lens and a wire-flame viewfinder is provided on one side. Any 16mm motion-picture lens with a type "C" mount can be used. With this system there can be only the simplest type of static pickup.

For more versatility a 20-to-60mm Zoomar lens can be used with the



Block diagram of installation at Wheelus Field, Tripoli, and Dhahran, Saudi Arabia (RCA Engineering).

broadcast vidicon. An optical viewfinder is included, but an adapting plate is needed to mount the lens, and an expert cameraman is needed to achieve good results when any movement is present.

The camera should always be mounted on a tripod. The Professional Jr. Model MS is a fairly sturdy unit which consists of a wooden tripod and a friction head that permits individual control of the pan and tilt. A tripod dolly provides mobility.

Control Equipment

From the camera a single 15 conductor (3 coaxial) 50-ft cable brings the video signals to the camera control monitor. Incorporated in the monitor case is a power supply, control panel and picture monitor. From this single control position the operator has full control of the vidicon camera including its electrical focus, mechanical focus and beam intensity. In addition a full view monitor of the picture quality is obtained on the 10FP4 aluminized picture tube. Unfortunately the cameraman never knows when this is going on. Brightness, contrast and black level controls for the monitor, and adjustable circuit controls, are located beneath the snap-on metal cover just below the picture tube.

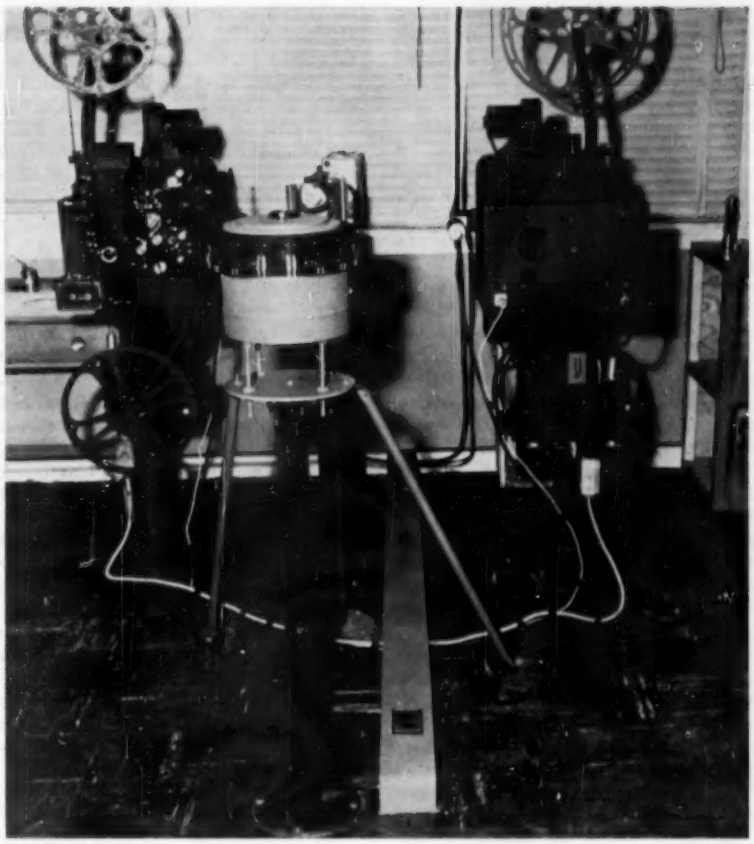
The output signal from the vidicon camera chain is provided at a single coaxial connector and measures 1 v. This composite video signal can then be fed directly to the television station's video signal system and hence to the transmitter. The output signal can also be used to feed a number of picture monitors.

Transmitting Equipment

The video signal at Loring is derived from an RCA picture modulated r-f generator. The TX-6468B Television Picture Generator is a compact, low-power, signal source for low channel operation. Amplitude video modulation is obtained from an external composite video signal. The r-f carrier is produced by a high stability heater-oven type of crystal oscillator and the necessary frequency multiplier stages to drive the video modulated power amplifier. The necessary components are mounted on a standard rack type of panel and chassis including suitable shielding. This is, in effect, a piece of test equipment modified to meet this particular requirement. It operates in conjunction with the TX6466 Sound Generator to feed a signal to the antenna.

Antenna

At Loring Air Force Base and at Wheelus Field in Libya where a similar installation is in operation, a pylon-type antenna is employed. The physical location of the Loring housing and barracks areas presented a special problem. In order to yield equal signal strengths in all directions from the antenna site a circular horizontal antenna pattern is desirable. The antenna in use yields approximately the required radiation pattern for both sound and picture.



Film Projectors (Holmes) and Slide Equipment (Spindler-Saupe) at Lajes Field, Azores. The same equipment is in use at Keflavik, Iceland.

The pylon antenna consists of a vertical aluminum pipe supported at its base by means of bolt connections to the attached flange. The radiators consist of three slots cut into the walls of the pipe in a longitudinal direction and fed by a solid dielectric coaxial transmission line. Weather protection for the radiators is provided by an antioxidant polyethylene cover for the slots. This material has been proved through long commercial outdoor use. No de-icing facilities are required with this type of antenna. Condensation inside fittings and stubs is, however, a problem. Since there are no elements protruding from the pipe, the design lends itself to ease of shipment and erection, while offering a minimum of wind resistance. The top of the antenna is capped to protect the inside of the pipe and feed system and lends itself to beacon mounting. Although the constructional material may be painted, no protecting finish need be applied. This type of antenna requires a minimum of maintenance.

The antenna was received, pretested and completely assembled, requiring only erection and simple radio frequency transmission line connections from the transmitters. The use of three radiators removes the need for diplexing since one radiator is assigned to aural radiation, while the remaining two radiate the picture signal.

The lightweight construction allows the mounting of this antenna on existing buildings or light-duty towers. At present it is installed on a 200-ft guyed antenna tower such as you see in everyday use by commercial TV stations.

Audio Equipment

As in any first-class small TV operation the audio equipment includes 3-speed turntables, consoles, tape recorders and associated equipment. As was expected, the demand for a greater "live" capability was soon generated not only at Loring, but at other locations where television stations were desired.

Potential Expansion Necessary

As had been expected, at Loring and elsewhere demand for more "live" capability developed. From a production standpoint it became evident also, that the equipment originally installed at Loring

was inadequate. The demand arose for better studios, and for equipment necessary to operate a smoother film presentation, as well as to present more "live" shows. Since it was desirable not to mix types of equipment, the vidicon camera at Loring was relegated to film pickup alone. Multiplexing equipment was procured, and two image-orthicon camera chains were installed.

A number of disadvantages attach to the use of image-orthicon chains in an operation such as AFTV. While the signal from the image-orthicon camera is theoretically better than the 6326-type vidicon, the signal delivered to, and by, the transmitter is indistinguishable except with the highest quality test equipment. This is true only, of course if studio conditions are identical.

Any smear resulting from sudden movement of, or before, the vidicon camera, is offset by the tendency of the image orthicon to stick, as it ages or is left on a static subject for prolonged periods. In other words, the image orthicon will not of itself produce a better picture on the viewer's set. It requires more precise operation and better maintenance, as well as better all-around handling to get better results than can be secured from the vidicon. A major disadvantage, of course, is the difference in price. The cost of an image-orthicon chain is approximately two to three times that of a vidicon chain.

As stated before, the absence of an electronic viewfinder on the RCA vidicon camera has presented a serious drawback to studio use. The "field operators"—the men who operate the cameras in our stations—demand some such device. Anyone who has ever operated a press-type camera knows the difficulties connected with using the wire viewfinder. TV camera operators find this device impossible to use.

Investigation of available equipment led to the Dage TV Division of Thompson Products and to the Dage 300D camera. Essentially the two cameras vary little except in the addition of an electronic viewfinder to the Dage equipment, and a more definite control of the picture by the camera operator.

The Dage System, like the RCA, is "broadcast quality" as required by AFTV Specifications. This camera has successfully operated at around 50 ft-c and gives excellent results at 75 to 100 ft-c. It is equipped with a 3-inch viewfinder tube which is successfully linked to a magnifier giving an effect obtained from the usual 7-in. viewfinder scope. It is also equipped with a lens turret mounting three lenses. Focus is controlled by the cameraman.

A criticism leveled at this camera has been the smallness of the viewfinder scope. In actual practice this has not been found to be justified.

A complete Dage-engineered package was procured and placed in operation in the Azores on 17 October 1954. Since that time no deficiency has been reported from this station and no modifications have been requested except for a more stable base and variacs for projectors.

Production-Line Installation

An entirely new method of designing and engineering a TV package was followed in the installation at Lajes Field, Azores, and at Keflavik, Iceland. This method, developed by Dage engineers in collaboration with Department of Defense agencies, is so simple as to appear almost obvious. It consists essentially of gathering all elements needed to establish a station, completely assembling the station, operationally testing the unit, unplugging the major components and transporting them to the location, setting up and going on the air.

While it is technically true that the station owner is expected to do a systems engineering job with his own personnel, this has not always been possible with the Armed Forces Television outlets. Shortage of engineers experienced in television has been the major reason for this lack of systems design by AFTV.

Time has also been a large factor in this operation. It has been necessary, therefore, to call upon the equipment industry for more help than might be the case under other circumstances. This need made mandatory some form of production-line technique for the installation of AFTV outlets.

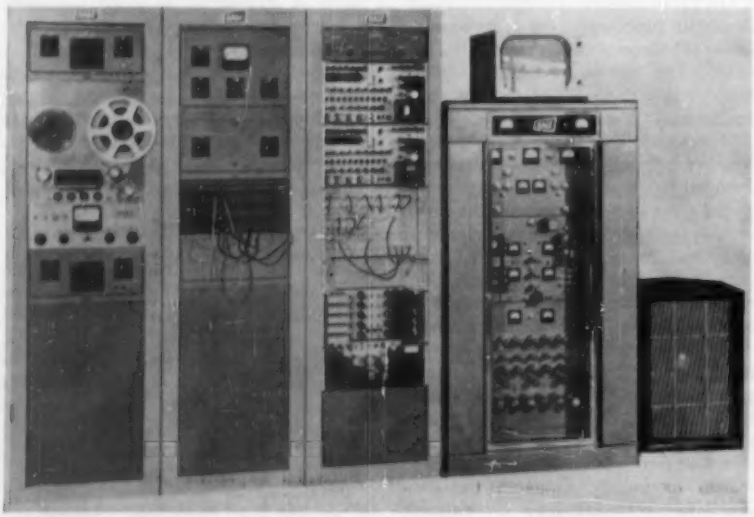
First, a site survey is made of a proposed location and a suitable building is selected. This is usually a building requiring a minimum of alteration and entailing a minimum of diversions. Drawings and layouts of the building are supplied to the contractor, and all government-furnished equipment is delivered to his plant. It then becomes the responsibility of the contractor to integrate this government-furnished equipment into the complete system.

All equipment, including the audio, film, video and transmitter is assembled in accordance with the proposed layout and a thorough system check is run. At this time required inspections are made by the procuring agency.

The complete station is now ready for shipment, which is usually done by special airlift. By flying the station to its new location overseas packing is avoided, saving time and money.

Once at its destination, the station equipment is reassembled and turned on. An example of the efficacy of this course of action is shown in the case of Lajes Field. The Lajes contract was signed on 7 September; government-furnished equipment was delivered to the contractor 20 September; the complete assembly left the contractor's plant 4 October; the station began scheduled programming 17 October. In other words, in 41 days — including Sundays and holidays — from the signing of the contract, the station was on the air.

In the case of Keflavik, Iceland, a total of 107 days elapsed from the completion on 18 November of the site survey until 3 March 1955, when the station began operation. Again this is actual chronology, with no time out for weekends.



Left to Right—1 & 2: Audio racks; video rack containing sync generator and associated equipment. Extreme Right: transmitter, designed by Electronics Research Laboratory, Hollywood, for Dage Television Div., Thompson Products. Installed at Keflavik, Iceland.

Programming

Programming has presented a major problem if not the most difficult problem encountered in the setting up of AFTV.

Since TV for the purposes under discussion is an unprogrammed activity, in the sense that no budgetary action preceded the actual beginning of operations, no funds are available for programming. It is doubtful, moreover, if expenditure of any proportion will ever be available for this purpose.

A part of the original concept of AFTV sprang naturally from the years of experience with Armed Forces Radio Services. Their programming was accomplished by transcribing network-produced shows, and distributing the discs to AFRS stations. This amounts to somewhere around 500,000 transcriptions a year. While other programs are supplied the bulk of AFRS program material comes from sources within industry.

AFTV similarly turned for program material to advertisers, agencies, TV film producers and networks for permission to use kinephoto recordings of commercially produced programs. Craft unions and guilds were approached and readily provided waivers of contract clauses governing the re-use of these kines. Prints were made available by advertisers and networks, and at the present time an average of 60 hours of program material is shipped each week to AFTV outlets.

So far only one print of each program has been shipped each week. These circuit from Loring AFB to Lajes Field in the Azores, to Wheelus Field, Tripoli, and then to Keflavik, Iceland.

A delay of only a few hours in airplane schedules can easily put us out of business for quite a time. The loss of a shipment outright would be disastrous — and "catastrophic instability of heavier-than-air craft," under certain circumstances is still a fact. We can lose a shipment!

Personnel

The manning of AFTV outlets is also a problem area; personnel must be secured from within available troop spaces. Currently the stations are being manned by personnel from Information Service for production jobs, and from the Electronics Career field for technical operating and maintenance positions.

Each AFTV outlet uses eight to ten men, depending on the hours of operation. This staff consists of *Station Manager* (usually the base Information Service Officer), and airmen taking the positions of *Chief Production Assistant, Production Assistant, Projectionist-Film Clerk, Chief Engineer, Engineering Assistant, two Maintenance Technicians,* and *Cameraman-Engineer.*

Camera controls, switcher and audio console of Keflavik AFTV Station. Audio equipment is Gates SA40 Console and CB4 Turntables.

Personnel chosen for the positions are required to take two to three weeks special training in each of their specific fields prior to the station's going on the air. Engineering personnel get their training from the manufacturer of the equipment. The individuals chosen for the production position are if possible, given brief training at a commercial television station depending upon their experience and qualifications.

Costs

No area of AFTV Services presents a more varied picture than that of costs. Total investment at Loring Air Force Base approaches $70,000 while Lajes Field represents an expenditure of less than $50,000. Approximately $55,000 will cover the Tripoli installation, while Keflavik ran slightly over $47,000. When you consider that Keflavik and Lajes are 50-w outlets, both represent a better equipment buy than the other installations.

The costs at these two stations represent total outlay including integration of government-furnished equipment, training of personnel and installation. They do not include transportation costs. Shipment, however, is usually made by regularly scheduled transport aircraft, and no additional expense is involved. These figures do not include modification of buildings which, varying with the location and local labor costs, will average about $10,000.

Future Plans

A look into the future reveals plans for some 20 to 30 outlets to be established within the next two years, though it is not likely that the number of television stations will equal Armed Forces Radio Networks for many years. Outlets are planned for such locations as Thule, Sondrestrom and Narsarssuak in Greenland, Puerto Rico, Bermuda, Johnson Island and Okinawa in the Pacific, and other isolated areas where English language television programs are unavailable or inadequate.

No additional broadcasting stations are planned for the continental United States. Few locations are so isolated that they cannot be served by booster stations or community-type antenna systems. Construction of installations such as these is being considered.

Many factors, including geographical location, isolation and local government attitudes, influence the growth of Armed Forces Television. But these factors must not hold back the orderly, planned development of a television service for Armed Services personnel in those areas where television's ability to recreate the sights and sounds of home are most important.

A System of High-Speed, High-Temperature, Reversal Processing

By LESTER E. BERND

A new 16mm processing machine accomplishing a 48-sec reversal processing cycle is described. This machine was designed and engineered for the Delaware Steeplechase and Race Assn. by the EDL Co. of Gary, Ind. To the best of the author's knowledge, it is the first spray-type processor designed particularly for high-temperature reversal processing. This paper also relates the history of high-speed reversal processing as done by the Delaware Steeplechase and Race Assn.; gives the reasons why thoroughbred racing requires film records to be processed rapidly, and traces the progress from 1945 to the present.

Thoroughbred racing has been utilizing 16mm motion pictures for several purposes for the past ten years. In this field perhaps, more has been done to encourage high-temperature reversal processing techniques than has been done by any other type of organization. Some of the reasons that racetracks became interested in motion pictures and especially high-speed processing are briefly as follows:

(1) To provide a record of the running of every race to be used by officials in making decisions concerning infractions occurring during the running of any race.

(2) To be used as a school for jockeys; to develop better riding.

(3) For owners and trainers of thoroughbreds to study the "running habits" of their horses.

(4) To provide a permanent record which can be referred to years later, if necessary.

(5) To be used for television.

The reason for high-speed reversal processing is to be able to screen the races within minutes after the actual running so that the officials might use them as an aid in making a decision in the case of an official inquiry. Thus, it can be seen that speed in processing is essential in order not to keep thousands of people waiting, and also not to delay the post times, which could prove to be costly to a race track.

Description of Film Patrol

This paper will describe the rapid processing system as used by thoroughbred racing, before describing the latest processing machine which effects a 48-sec reversal cycle. This system is known generally to thoroughbred racing as the "Film Patrol." There are in existence at the present time several companies under various names providing this service to race tracks. This paper will be restricted to the system as used by the Delaware Steeplechase and Race Assn., owners and operators of Delaware Park.

The Film Patrol is a method of coverage of thoroughbred races in 16mm motion pictures. At Delaware Park there are seven camera positions strategically located around the outside oval of the race track. These positions are, for the most part, 35-ft steel towers, of I-beam construction, with an enclosure at the top. In these towers are located a cameraman with a 16mm camera and lenses of various focal lengths, depending upon the cameraman's location. Each man photographs a segment of the track during every race. The cameras are unloaded immediately after every shot and the exposed film sent to a waiting courier below, who speeds it to the laboratory. The laboratory immediately begins processing of this film by reversal, and in a matter of minutes the reversed positive image is projected for the officials if they should desire it.

Much time and money has gone into perfecting a system of pickup from the camera positions and delivery to the laboratory.

History of the Film Patrol

The history of the Film Patrol, as we know it at Delaware Park, is here given to the best of our knowledge. Sometime in the year of 1945, at a Thoroughbred Racing Assn. convention in New York, this system was described by a California race track. The first technique of processing was by rack and tank. Water spots, staining and reticulation were common troubles. Added to that were the limitations of temperature which the then existing emulsions could withstand. It is believed that in that same year the Houston Corp. built the first machine expressly for high-speed reversal processing.

By 1946 the system had spread from California, where it had been made mandatory, to eight eastern tracks, among which was Delaware Park. At this time, this service was supplied by a commercial company. The total lapsed time for posting an official decision by using the pictures as an aid, was nearly 20 min which, of course, was objectionable. However, the potentialities of the system were recognized, and with the support and confidence of thoroughbred racing, improvements were soon to be made.

Types of Film

The film used at the beginning was Eastman's Super-X available commercially, with the processing included. There was a problem here of properly removing the black base and, as a result, the Eastman Super-X blue base film Type 5275 was substituted, due to the ease of processing. This film was used extensively by the Armed Services during World War II.

In 1946, a standard stock processing machine, built by the Houston Corp. was slightly modified, and as a result, the processing time was decreased to about 8 min. It was here that the Du Pont Co. introduced the Type-330 emulsion. For the next several years, all the research was done around a modified 11B Houston machine, and in 1950, processing time was 5½ min. It seemed that no further progress could be made because the film then available could not withstand the temperatures and swift handling necessary with the main difficulty being reticulation.

At this time, Du Pont, working hand in hand with the Delaware Park photographic department, developed the new super hardened Type 930 Rapid Reversal Pan. This has proved to be the greatest single factor in our present-day success. This new film, in 1953, immediately allowed the processing time to be reduced to 3 min. It was quickly recognized that the film could withstand even higher temperatures but the processing machine we had could not be further modified to exploit the new film's potential. Therefore, Delaware Park commissioned the EDL Co. to build a new processing machine able to take full advantage of the film's capabilities. This machine, the DM 11, was installed in May of 1954, and as a result of its operation through the 1954 and 1955 Delaware Park meetings, much has been learned and several improvements have been made.

Delaware Park first installed the Film Patrol in 1946, contracting for the services of the Throughbred Photo Service in that year. In 1947, Delaware Park formed its own Film Patrol. In 1948, the writer was hired to head their

Presented on April 21, 1955, at the Society's Convention at Chicago by Lester E. Bernd (in season, Delaware Steeplechase and Race Assn., Wilmington, Del.), 11 Comeau St., Wellesley Hill 82, Mass.
(This paper was received on April 22, 1955.)

Table I

Compartment	Film capacity	Processing time
1st Developer	8 ft	10 sec
Bleach	4 "	5 "
Clear	4 "	5 "
2nd Developer	4 "	5 "
Fix	4 "	5 "
Wash	4 "	5 "
Dry	4 "	5 "
	32 "	40 "
Rinses between tanks	6.5 ft (Length due to threading to prevent solution losses)	
Take off Elevator	3 ft	
	41.5 ft @ 52 ft/min = 48 sec	

photographic department. It might be mentioned here that no dividends are paid to the stockholders of Delaware Park. Instead, any profit realized is spent in improving the various departments for the good of the sport of thoroughbred racing. Consequently much time and money have been spent to perfect the Film Patrol as we have it at Delaware Park. Film Patrol is in use by nearly every major race track in the United States and in a few foreign countries.

General Description

The new EDL high-temperature, high-speed DM-11 processor utilizes spray application of solutions. Complete reversal processing is accomplished in 48 sec with the film dry, ready for projection. Table I gives the times for each stage of processing. The machine speed is 52 ft/min. It was felt that this speed should not be increased as it would inflict a hardship upon the operator splicing the film into the loading elevator.

The physical dimensions of the DM-11 (Fig. 1) are 24 in. wide, 69½ in. long, and 72 in. high. The machine is operated in daylight. Individual panel covers make the wet section processing compartments light tight. The machine is designed for attachment to a darkroom chamber. Both loading and take-off (Fig. 2) elevators are provided. The leader capacity of the machine is 41.5 ft. A 220-v, single-phase power supply is required.

Individual controls, thermometers and processing section are at waist level along the front of the machine. Master switches and controls are located at the far right (Fig. 3). The major electric control box is in the rear of the machine. Ordinary radiator hose can be used to connect to the drain. The air exhaust from the drybox is a 5 by 12 in. outlet which can be reduced to a 5-in. diameter duct to the outside. Indicating lights below each thermometer go out when the solutions are at proper operating temperature.

Fig. 1. Front view of the DM-11 processor with the compartment covers on for daylight operation.

Chemical Supply

At Delaware Park, the Film Patrol laboratory occupies two floors. Directly above the processor on the second floor is located the chemical mixing room and five 50-gal "stock pots" (Fig. 4). These contain the first developer, bleach, clearing bath, second developer and fixing bath. Mixing is done with a Pako Hydromixer. Tygon tubing connects the chemical supply through the floor to the

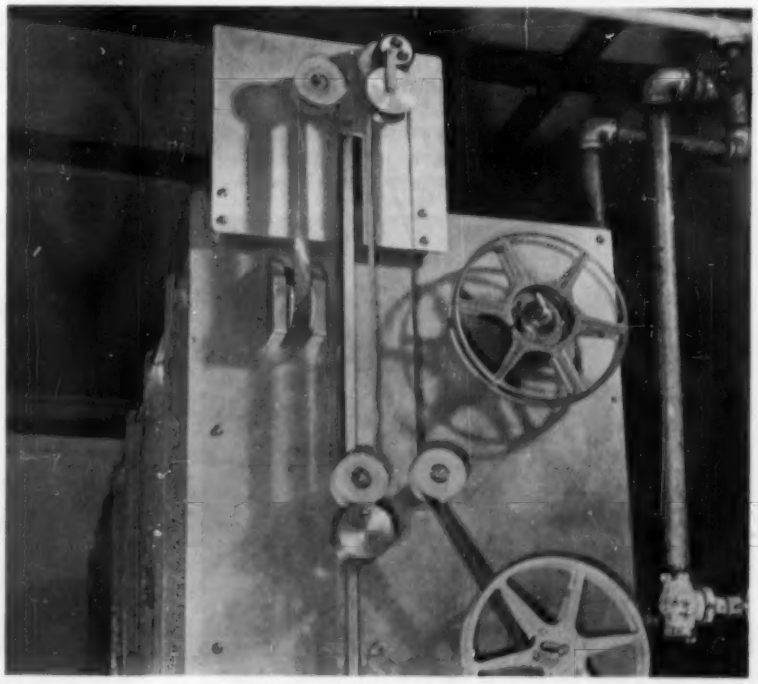


Fig. 2. Take-off elevator on dry-end of machine.

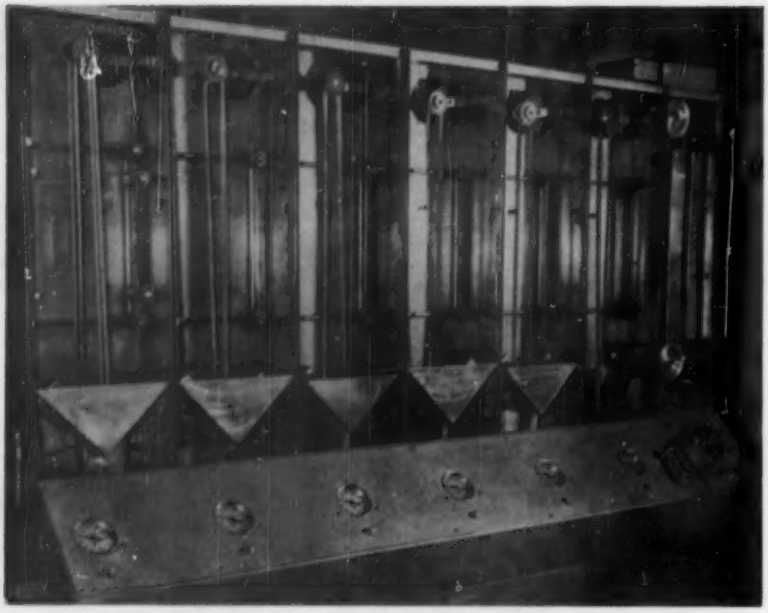


Fig. 3. Front view of DM-11 processor with compartment covers off.

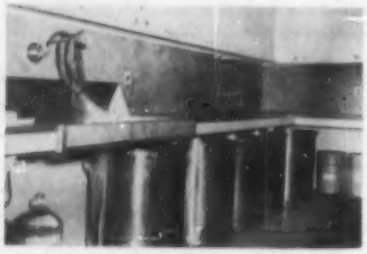


Fig. 4. Second floor chemical-mixing room.

proportioning pumps (Fig. 5) on the machine below.

Solution Path

Fresh solution for replenishment, accomplished automatically, is pumped into preheat tanks at the rate of approximately 0.1 gal/min. The rate of replenishment can be adjusted by lengthening or shortening the stroke of the proportioning pumps. The preheat tanks, of approximately one-gallon capacity, contain a standpipe at the same level of the sumps in the processing compartments. Fresh solution enters the circulating system by means of overflow into this standpipe. The solution then joins the used solution and enters the input of the circulating pumps (Fig. 6), after first passing through 1500-w heating wells which accurately maintain operating temperature by means of an on-off Fenwal thermostat.

Double stage, $\frac{1}{4}$ hp circulating pumps are used for all solutions except the first developer which is $\frac{3}{4}$ hp. These pumps force heated developer through mesh wire screen strainers to the spraying nozzles in the processing compartments (Fig. 7). Each compartment has four spray nozzles with the exception of the first developer compartment which employs eight. These nozzles apply solution at a pressure of 30 psi. A flat vertical spray is directed parallel to the film strand.

Excess used solution falls into the sumps where it overflows to the drain. The remainder of the used solution returns to the input of the circulating pumps where it is joined by fresh solution and recirculated. The sump solution capacity is 40 cu in. with the exception of the first developer which is 60 cu in. The immersion type dial thermometers register the temperature on the output side of the solution pumps.

Film Drive

The film travels in a helical path with crossovers at the bottom of each compartment (Fig. 3). Film drive is accomplished by sprocket rollers located on the top shaft of some of the compartments beginning with the first developer. Each compartment contains a single strand of film except for the first developer which has two. Shrinkage or expansion of the film is compensated for by the free top rollers that do no driving. In these instances the top roller assemblies move up or down by means of a triple gear arrangement that is counterbalanced.

Formulas

The formulas used are those published by Du Pont with a few slight modifications. These formulas appear in Du Pont's publications Nos. A-7805 and A-7876. Kodak Rapid Liquid Fixer with hardener was used with dilution of four parts of water to one part fixer. Considerable difficulty with fog was encountered at first but has been eliminated

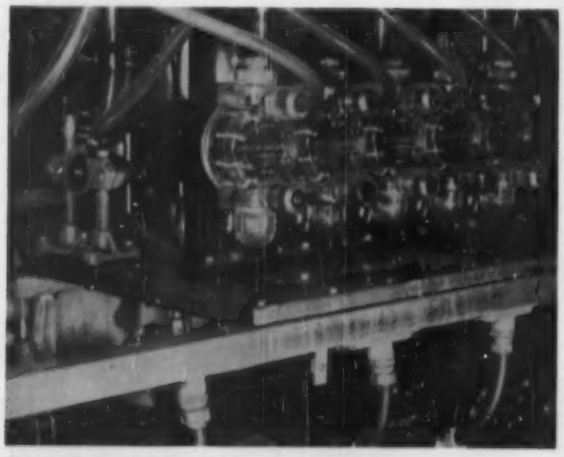


Fig. 5. Rear, close-up view of the DM-11 processor showing the proportioning and circulating pumps.

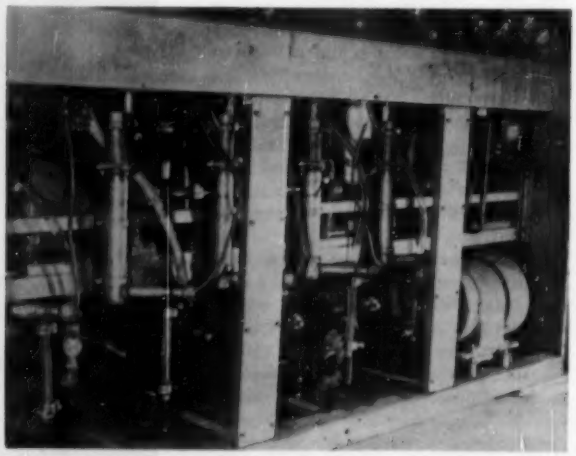


Fig. 6. Front, close-up view of the DM-11 processor showing the circulating pumps and solution heaters.

Fig. 7. Close-up of processing compartment. Re-exposure well can be seen in bottom of center compartment. Spray nozzles and drive rollers also can be seen.

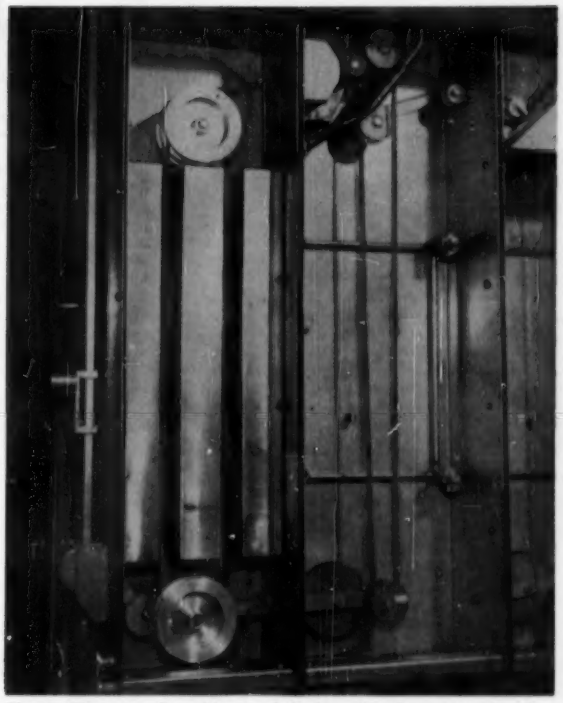


Fig. 8. Close-up of washing and drying chambers. Squeegeeing unit can be seen in bottom of washing compartment

with the use of Kodak Anti-Fog No. 2.

Rinsing

Tempered water, controlled by a Powers mixing valve, is supplied to rinsing nozzles between each compartment. Water is applied to both the top and bottom of the film strand as it passes horizontally from one compartment to another (see bottom of center section in Fig. 7). Re-exposure occurs as the film enters the second developer compartment. Light for re-exposure is supplied by three 30 candle power tungsten incandescent bulbs.

Squeegeeing

Effective squeegeeing is highly important in rapid drying. Considerable difficulty was originally encountered in removing completely all water from the film before it entered the drying chamber. This trouble was overcome by the liberal use of air pressure provided by a Roots blower driven by a 1-hp motor. The air squeegeeing is accomplished below a baffle in the bottom of the wash compartment (Fig. 8).

Washing

Washing is accomplished by four spray nozzles arranged similarly to the processing compartments (Fig. 8). This water is also maintained at processing solution temperature.

Drying

A $\frac{1}{2}$-hp blower supplies heated drying air to three plenum chambers in the drying compartment (Fig. 8). Three 600-w heaters are employed and can be used in any combination. The heated air is impinged upon the emulsion side of the film from 128 holes, 0.080 in. in diameter, over a 51-in. path. A lesser number of holes apply pressure to the base side of the film as a means of balancing to keep the film centrally positioned.

Drying is accomplished in 5 sec.

Take-Off

As the film leaves the drying chamber it passes through a take-off elevator requiring three feet of film for threading. This take-off elevator allows us to "break down" the film while the machine is still running.

Temperatures

Accurate temperature control of all solutions was originally held at 125 F. In order to bring solution temperature from ambient, which averaged 65 F, it was necessary to preheat before the solutions entered the circulation system. However, as a result of a season's operation, it has been learned that 110 F was adequate for the 48-sec processing cycle and that the preheaters were no longer necessary.

Solution operating temperatures are easily maintained by the heaters in the circulating system. The exposure index of the film due to the elevated solution temperature (from 68 F) has been increased effectively from 80 to 120. The temperature of the fixer, rinse and wash water is also held at 110 F.

Inasmuch as the operation of the machine is intermittent during the day, the hot water supply has so far been no problem.

Conclusion

The resulting quality of the Type 930 Du Pont Rapid Reversal Pan processed in 48 sec has been consistently excellent. Further, very gratifying results have been attained in processing single-system sound which has been very acceptable for television. Thus it has allowed Delaware Park to produce "spot news" television shorts and present them to the stations only minutes later. Due to our increased speed in getting our racing pictures on the screen, Delaware Park will this year install a closed television system for transmitting pictures from the laboratory to the stewards' stand which will practically eliminate any delay in making a race official where an inquiry is involved.

The success of the EDL Model DM-11 processor has brought about a new, more compact design which will soon be in existence.

Acknowledgments

The author wishes to express his gratitude to: Donald P. Ross, President of The Delaware Steeplechase and Race Assn.; Bryan Field, Vice-President of the Delaware Steeplechase and Race Assn.;

Ted Harding, Motion Picture Products Manager of Du Pont; Edward Warnecke of the Eastman Kodak Co.; and Paul Ireland and Frank Draschil of the EDL Co. Without the unlimited support and encouragement of these men, the system we have today at Delaware Park would not exist.

Discussion

Paul Ireland (EDL Company): Have you any idea how Type 931 film would be with this process?

Mr. Bernd: I have not made extensive tests with Type 931. It has been my experience in the past that the higher speed emulsions seem to be heavier and harder to reverse. Preliminary experiments have indicated that it will elevate the ASA rating considerably and also that 931 is going to offer no great problem in reversing very rapidly.

George Lewin (Signal Corps, Pictorial Center): It is worth noting that detail in the picture seemed remarkably good considering the unusually fast processing. You expect to lose detail at such a speed. Have any comparisons ever been made as to whether or not you ever lose anything? I would almost say that you gain.

Mr. Bernd: In past papers in the Journal and from past experience, I would say that the spray application of processing solution has much to offer as far as increasing the quality over the bath system.

Mr. Lewin: Is this the original reversal film?

Mr. Bernd: Yes. I have no idea how often this film was used but, conceivably, it could have been projected a dozen times. There is comparatively little abrasion even though the film is what you might call "green."

Mr. Lewin: Have you ever put soundtracks through the same process?

Mr. Bernd: Yes. The soundtrack is very good. Probably one of the most gratifying things about the whole process is the fact that single-system sound is so good considering the "beating" that the film must take.

Mr. Lewin: Do you bother putting soundtrack on these official race films?

Mr. Bernd: Not at present. We are seriously considering the Minnesota Mining Laminating Machine for laminating the track on this film later on in the day for stewards and officials to make any notes for the permanent record that they might desire, and I'm glad to learn that television stations can now take audio off a magnetic stripe, which will open up an entirely new field of publicity for us in utilizing these race films.

Mr. Lewin: Would it be of some value to have the announcer's voice recorded?

Mr. Bernd: Yes, but it would introduce a problem, as these cameras do not all operate at the same time and are not synchronized with each other. The film would have to be edited down to fit the soundtrack because it is practically twice as long as the actual race itself.

Infrared Motion-Picture Technique in Observing Audience Reactions

By BERNARD R. KANTOR

This paper describes, in detail, an installation and a procedure by means of which a motion picture, on infrared sensitive film, may be made of an audience as they watch another film being projected on the screen. Specifications are given for light sources, exposure and development.

PROCEDURES by which a research worker may observe the reaction of a motion-picture audience have been sought for many years. In 1931, a large group of persons was photographed in total darkness in an auditorium at the Kodak Research Laboratories using an Eastman Infrared-Sensitive Plate and an exposure of 1 sec at *f*/3.5. The exposing source consisted of 15 1000-w studio-type lamps enclosed in a box with the open side pointed toward the ceiling and covered by a Wratten Filter No. 87. Audience-reaction photographs were made on Kodak Infrared Sheet Film in 1945 in this same room during the projection of a motion picture. Three Kodatron lamps were used in a box with its open side toward the ceiling and covered by a No. 87 filter. The exposure time was 0.0001 sec at *f*/3.5. These studies are described by Clark in his book *Photography by Infrared*.[1]

Presented on April 19, 1955, at the Society's Convention at Chicago by Herbert E. Farmer for the author, Bernard R. Kantor, Dept. of Cinema, University of Southern California, University Park, Los Angeles 7, Calif.
(This paper in revised form was received Sept. 28, 1955.)

Successful efforts were also made by Dr. Nicholas Rose at the University of California at Los Angeles in 1950 utilizing still pictures, and later under the auspices of the Human Resources Research Laboratory using motion pictures. The work described herein is based on those experiments and was carried out at the University of Southern California, Dept. of Cinema, under U.S. Public Health Service Grant No. 3M 9066. This project is being conducted under the direction of Dr. Lester F. Beck; in addition to the author, Loriene Johnston and Charles Van Horn are associated with the work.

The Theater

For the purposes of this experiment, a small room was remodeled to function both as an experimental and a preview theater (Fig. 1). This room is 25 × 13 ft with a 10-ft ceiling; it seats 25 people in five rows of tablet arm chairs. A large plywood baffle is placed in a front corner, at the side of the picture screen; the purpose of this baffle is to conceal the camera from the audience. Above the camera port, a dummy speaker grille has been added to give the baffle an appearance of serving a purpose other than camera concealment (Fig. 1).

A 16mm Mitchell camera, controlled from the projection booth and blimped for silent operation, is fixed to a 6-ft steel cylinder which is bolted to the concrete floor, since the available space does not permit the use of a tripod (Fig. 2). The distance from the lens to the nearest seat is approximately 7 ft; when focused at 12 ft, a 15mm lens gives satisfactory coverage and focus over all five rows. No filters are used at the camera.

The Light Source

Normal lighting in the room is provided by ordinary flush-type ceiling lights. In addition, nine bullet-type fixtures are mounted in three approximately spaced rows on the ceiling. Using ordinary incandescent bulbs and an exposure meter, these lights were adjusted to give equal illumination over the entire area covered by the camera; the bulbs were removed and replaced by the infrared bulbs to be described below, care being taken not to disturb their adjustment. The fixtures are mounted to throw their beam toward the audience at an angle of 45°; this keeps the visible portion of the light away from the screen, and eliminates the deep shadows which would result from lights immediately overhead.

Fig. 1. The front of the research room with both enclosures in position.

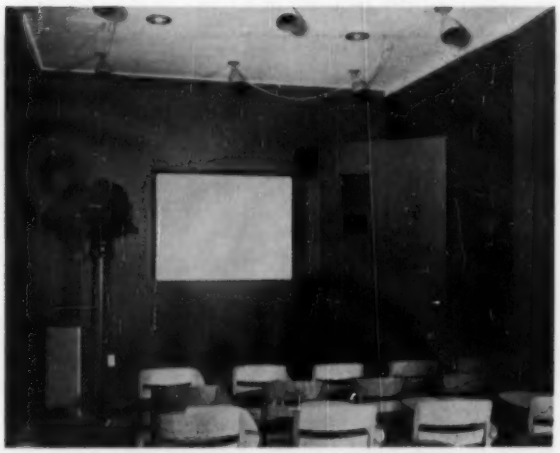


Fig. 2. The front of the research room with only one screen in position. The cylinder which supports the camera can be seen.

The circuit for these lights terminates in the projection booth where a variable voltage transformer is placed in the circuit; in this way, one operator may control the illumination and operate both projector and camera.

Filters

The principal requirement for a light source in this case is that it provide a maximum of those wavelengths to which the film is sensitive, and a minimum of visible light. Experimentation has indicated that 150-w PAR 38 projector flood bulbs, coated with an infrared filter, fulfill this specification. The filter material is a modification of a formula developed by R. B. Morris and D. A. Spencer of the Kodak Research Laboratories, Wealdstone, Harrow, Middlesex, England, for coating flash bulbs.[3]

The filter coating for bulbs contains:

Eosine conc	4 g
Tartrazine conc	6 g
Violet 4B conc	4 g
Green NV 150% or 100% conc	10 g
Gelatin Power, good chemical grade	200 g
Glycerin, good chemical grade	100 cc
Water	1000 cc

The gelatin is soaked for about an hour in 500 cc of the water at 70 F, then heated to 110–120 F and stirred until all dissolved. The four dye powders are dissolved separately in small quantities of warm water (not more than 150 F); all are readily soluble except the Violet 4B which must be added to water a little at a time and completely dissolved before the next addition. Each dye solution is diluted with an equal quantity of gelatin solution before it is mixed, to protect against precipitation. The glycerin is diluted with an equal quantity of water at 120 F before it is added to the solution and the solutions of the ingredients are mixed together. The rest of the water is then added and the entire solution filtered through two layers of muslin to remove undissolved particles and air bubbles. Except when preparing bulbs, this solution should be kept refrigerated as it has grown mold quite readily.

Preparation of the Bulbs

The dye solution is applied to the bulbs by dipping; the clean bulb is immersed in the solution to a depth of one inch, slowly withdrawn, and rotated slowly in the hand for several minutes until the mixture has begun to set, to insure uniform thickness. Practice with one or two bulbs should be sufficient to develop a technique which will yield uniform coatings free of air bubbles.

After at least 4-hr air drying, the bulbs are burned for 2 hr at 30 v to cure them. A board on which several sockets are mounted is convenient for drying, curing and storing coated bulbs.

Thickness of the coating is controlled by the temperature of the solution into which they are dipped; all bulbs used in this study were given four separate coats of the material at 96 F. This temperature is quite critical if uniform coatings are to be obtained, and must not be allowed to deviate more than one degree in either direction. Four such separate coats, each dried before the next coat is applied, reduce the visible light to a level which does not distract the audience; a thicker filter effects very little reduction in visible light but increases the exposure necessary.

Bulbs coated in this way will burn about one hour at 110 v before the coating softens and chars. For the experiment conducted with this procedure, the bulbs were operated at 70 v; this reduces the amount of visible light and greatly increases the life of the coated bulbs.

Film and Processing

All camera tests were conducted with Eastman High Speed Infrared Film. Using bulbs coated as described, and burning at 70 v, an exposure of $f/4.0$, with the shutter set at 235° and the camera running at 24 frames/sec gives a suitable exposure. The film is slightly overdeveloped, to a gamma of 1.1 in modified Kodak D-76. This negative can be printed satisfactorily at the middle range of a Bell & Howell Model J Printer. The film must be processed in complete and total darkness.

In use in the research project for which this procedure was developed, an audience is photographed under infrared light while they watch an 8-min film. This is followed by a 20-min discussion period which is photographed on the same film at the same exposure under room lights which provide about 16 ft-c of visible light at the desktops. This is a considerable over-exposure, but can be printed at about seven printer points higher than the infrared exposure. The white light exposure on infrared film gives the characteristic "penetrating image," but for the purposes of the experiment, is entirely satisfactory.

Synchronized sound was provided for in this experiment by interlocking a recorder with the camera and projector (Fig 3).

In the course of the research which led to this system, tests were conducted using Eastman Tri-X Film. This film gave a normal image when exposed at 16 ft-c; but by over-developing, a fair image was obtained when the exposure was made at 2 ft-c at $f/2.5$ with other camera settings remaining the same as with the infrared film. From this it was determined that a film speed above 1400 was being used. The speed of the infrared film, when used with no filter, exposed to 16 ft-c of tungsten light, and developed to a

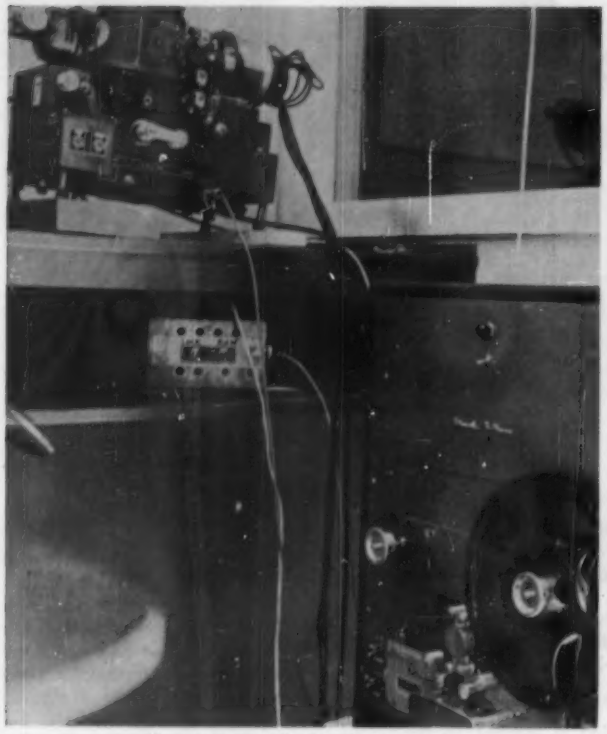


Fig. 3. Part of the interlock system.

Fig. 4. Blowup from three frames of Infrared Audience Reaction Film.

gamma of about 1.1 is well over 4000, computed on the same basis.

The actual research data were gathered with infrared film since it was decided that 2 ft-c of light, and Tri-X film, was entirely too much visible light for a darkened theater. The actual audience reaction motion pictures taken with the Tri-X Film were equal to those taken with Infrared Film. The decision to use Infrared Film was based entirely on the great amount of visible light in the room with Tri-X.

In photographing audiences while they are viewing motion pictures, infrared film and the techniques just described gave excellent results (Fig. 4). Photographing audience reactions without their being distracted or aware of the fact is possible and entirely practicable. The process is relatively uncomplicated and the cost is hardly more than ordinary cinematography.

Following the reading of the paper at Chicago, two 16mm sound films were shown. The first film, *Photographing Audience Reactions*, showed the facilities of the research room, described and illustrated the preparation of the bulbs and showed audience reaction footage of both Infrared and Tri-X film, pointing out advantages and disadvantages of each type of film. The second film, *U.S.C. Goofy Test*, is an infrared motion picture and synchronized sound record of a mixed audience of small children through adults (25 in all) viewing the Walt Disney cartoon, *How to Play Football*. The soundtrack included the sound from the film being viewed plus the laughter and remarks made by the audience. The picture was a visual record of the audience watching.

The author wishes to express his appreciation to the staff of the University of Southern California, Dept. of Cinema, Facilities, Production and Research Sections, whose excellent cooperation and unlimited patience made the development of this technique possible.

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1. Clark, W., *Photography by Infrared*, John Wiley & Sons, New York, 2d ed., Chapt. XII, p. 318.
2. Morris, R. B., and Spencer D. A., "Dazzle-free photoflash photography," *Brit. J. Photog.*, 87: 288–289, 1940.

A New Look at Colorimetry

By D. L. MacADAM

This is a report on the proceedings of the International Commission on Illumination (CIE) which met in Zürich, Switzerland, from June 13 to June 22. The status of the revision of the standard data for colorimetry is explained and discussed. The present FCC standards for color television are specified in terms of colorimetric data adopted by the CIE in 1931. Most quantitative work on color, during the past 24 years, has been based on the CIE data. The significance of the proposed revisions in relation to that work and to future work and specifications is discussed.

At a meeting in Zürich, Switzerland, June 13–22, a group of the world's leading experts on colorimetry faced the unpleasant necessity of revising the CIE data on colorimetry.

It may be recalled that the CIE color data played a prominent role in the development of the FCC standards for color television. From modest beginnings about 1937, the use of the CIE color standards in color cinematography has increased steadily, and the future growth of their application in the control of quality of color motion pictures, as well as in color television, can be forecast with confidence. Consequently, we have reason to be concerned about proposals to revise the CIE data.

First, let it be said that suggestions for revision do not mean that all of the results obtained in the past 20 years were wrong or need be changed. The great bulk of them were correct, as far as they went. The greatest need is for more and more like them. But colorimetry should be usable for work to which it has not often been applied, like selecting better and cheaper pigments, or deciding when a gray in a three-layer film is exactly neutral. Since the only tangible standards of neutrality, such as an image developed in motion-picture positive film, are physically quite different from the grays formed in three-color film, this is a difficult problem. The CIE colorimetric data should be capable of handling it, but they are not.

The first suggestion that the CIE data were not adequate to solve such problems came in 1948 when Jacobsen* attempted to substitute the rutile variety of titanium dioxide in place of the more expensive anatase variety in a white refrigerator enamel. The formulation he derived by use of the CIE color data was unsatisfactory and resulted in a creamy, rather than a white, surface.

About the same time, Judd, of the U.S. National Bureau of Standards, had trouble with some standard glasses which, according to the CIE data, should have matched certain grades of petroleum oil, but they did not match.

Shortly afterwards, we ran into trouble trying to select standard neutral gray areas in processed Kodachrome and Ektachrome films for calibration of color densitometers. Of course, different people select different neutrals. The Eastman Kodak Co. turned to the CIE data to referee this disagreement, but everybody agreed that the CIE data indicated a sample that was too yellow. If just as many people had said it was too blue as had said it was too yellow, we would have blamed their disagreement on personal differences and would have used samples selected by the CIE. But since all of us agreed that the sample indicated by the CIE data was too yellow, we had to agree with Jacobsen and with Judd that there was something wrong with the CIE color data.

To help us understand the story of the CIE 1931 data, let us define a term that will have to be used — *linear combination.* A linear combination is a result that is obtained by adding together fixed percentages of a number of variable quantities. To specify a color, only three quantities are needed: the amounts of red, green, and blue light that have to be mixed to match the color. Those amounts are called *color-mixture values.* For spectrum colors, they vary with wavelength. Their variations are shown by *color-mixture curves,* as in Fig. 1.

Suppose that at each wavelength one-twentieth of the number that specifies the needed amount of blue is added to the number that specifies the needed amount of green. Finally, to that total add one-half the number that specifies the amount of red needed to match the same wavelength. The result is called a "linear combination" of the color-mixture values. The result will change from wavelength to wavelength. That variation can be represented graphically by a curve similar to the color-mixture curves. In the case described, it is represented by the heavy curve in Fig. 1. That curve resembles the luminosity curve (formerly called the visibility curve), which is often said to show the spectral sensitivity of the eye for brightness. This similarity seems to be at the root of the troubles with the CIE color-mixture values.

The CIE data adopted in 1931 were based on the assumption that some linear combination of the color-mixture values should equal the luminosity value at every wavelength. Therefore, it did not seem necessary to determine actual color-mixture values experimentally. It was easier and seemed more accurate to determine only ratios of color-mixture values. Experimental data on ratios of color-mixture values were then adjusted to satisfy this assumption and to agree with the luminosity data adopted in 1924 by the CIE.

The difficulties encountered from 1948–50 were first attributed to certain errors in the 1924 luminosity data which, it was thought, by the method of adjustment, might have affected the color-mixture values. Revision of the color-mixture values in accordance with appropriate minor corrections of the

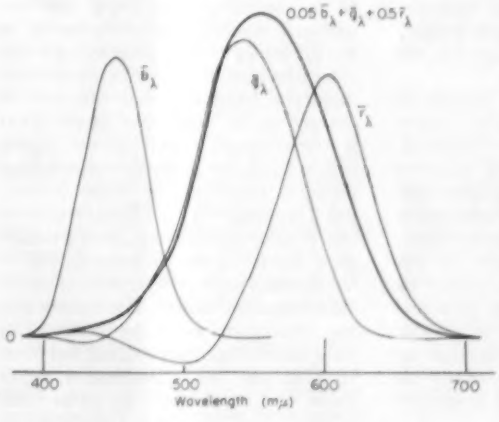


Fig. 1. Color-mixture curves, representing amounts of red ($\bar{r}_\lambda$), green ($\bar{g}_\lambda$) and blue ($\bar{b}_\lambda$) primaries required in a mixture visually matching equal amounts of each wavelength from 400 to 700 mμ. A linear combination of these color-mixture curves is indicated by the heavy curve. Based on Stiles's tentative data.

Presented on October 6, 1955, at the Society's Convention at Lake Placid, N.Y., by D. L. MacAdam, Research Laboratories, Eastman Kodak Co., Rochester 4, N. Y. Dr. MacAdam was an official delegate of the U. S. National Committee to the CIE meeting at Zürich.
(This paper was received on September 2, 1955.)

*A. E. Jacobsen, "Non-adaptability of the CIE system to some near-whites which show absorption in the far blue region of the spectrum," *J. Opt. Soc. Am., 38:* 442–444, May 1948.

luminosity data was proposed at the 1951 meeting of the CIE.

Postponement of action and direct determination of color-mixture values, without reliance on luminosity values, was advocated by the British committee. Stiles, of the National Physical Laboratory, Teddington, England, undertook the work and reported tentative results at the meeting in Zürich in June 1955. According to his results, no linear combination of color-mixture values can be made to agree with even the proposed revised luminosity data.

The decision therefore faces the Commission as to whether the connection between the color-mixture and the luminosity values, which was assumed in 1931, should be retained or abandoned. A decision on this point has been postponed until Stiles's final data are available. Confirmation of the most disturbing feature of Stiles's results by Sperling, working at the Medical Research Laboratory, U.S. Submarine Base, New London, Conn., makes it seem likely that one of the following two alternatives must be chosen: (1) we must abandon the connection between luminosity and color-mixture data and accept the possibility of contradictions between the results of photometry and colorimetry, or (2) we must adopt a revised luminosity curve significantly different from the present standard. According to this second alternative, the luminosity curve would be defined as a linear combination of directly determined color-mixture curves and would take into account only indirectly the great mass of experimental data on which the luminosity curve has been based in the past. Such data would be used only to determine the coefficients of the linear combination of color-mixture data which best fit the average luminosity data.

The proposed linear combination of directly determined color-mixture data will probably differ significantly from the present standard luminosity curve (adopted in 1924) in all regions of the spectrum. Although its maximum will occur at very nearly the same wavelength (555 mμ) as the present luminosity curve, it will probably be considerably wider, that is, less sharply peaked, and will certainly be much higher at the short-wavelength end.

Reluctance to accept such changes of the luminosity curve is readily understandable. Not only years of uniform, international laboratory and industry practice, but Federal law and also legislation of other countries have sanctioned the use of the 1924 CIE luminosity data.

Since the color temperature of the primary standard of light intensity (a blackbody at the temperature of solidification of pure platinum) is so low (2042 K), the luminosity curve must be used for photometry of very nearly all commercial lamps. The usual procedure is to prepare a color filter which changes the color of the light from the standard source so that it matches the light from the sample source. Photometric comparison of beams made to look alike by such filters is easy. All that remains to be done is to determine a "filter-factor" which specifies the reduction of intensity of the standard beam by the filter.

The legal way to determine that factor, and the only way to avoid personal disagreements, is to compute it by use of the luminosity data. Any revision of the luminosity data would force a revision of the factors that have been used for all such filters in the past. Consequently, all lamp intensities based on such factors should also be revised. This is a very serious matter for the lamp and illumination industries, which now provide most of the personnel and support for the CIE. It is estimated that the ratings of general-service, incandescent-tungsten lamps would be increased only 1 or 2%. But the ratings of daylight fluorescent lamps (and projection arcs, and kinescope tubes) would be increased as much as 10%. Some highly chromatic light sources (such as railway, automobile and aircraft signal lights) would be increased 100% or more. It is easy to understand the reluctance to accept a revision which would involve such important changes in so many large and different industries.

The other alternative is equally irksome. It could be expected to become increasingly obnoxious, particularly to the color-motion-picture and color-television industries. If the luminosity curve is not a linear combination of the revised standard color-mixture curves ($\bar{x}$, $\bar{y}$, $\bar{z}$), then colorimetric specifications might indicate that two physically different colors are alike in all respects and yet, according to the standard luminosity data, they would have to be reported as having different luminances. Since all reproductions in color motion pictures and color television result in colors physically different from the original colors, such contradictions and dilemmas would be potentially frequent and serious.

Perhaps the most serious effect would be in confusion of concepts and unnecessary complication of discussions of the principles of color photography and color television. For example, most of the frequency band for color television is devoted to the luminance signal. That is the compatible part of the signal, which forms the image in monochrome receivers tuned to the color telecast. But if luminance is not a linear combination of color-mixture data, then a luminance signal cannot be compounded of the signals from a perfect, three-channel, color-television camera. The camera and the transmitter might be designed to yield the true luminance signal, but then, in principle, the chrominance signal could not be designed so as to yield correct color reproduction when combined with that luminance signal.

Even though color-television cameras are not, and need not be, perfect, and even though the "luminance" signal is not, and need not be, perfectly representative of luminance, it is convenient, indeed almost imperative, to be able to talk in terms of the ideal. Such modes of discussion would be ruled out if the connection between colorimetry and heterochromatic photometry were abandoned by the CIE. To avoid this, the luminosity data would have to be redefined as linear combinations of color-mixture data; however the latter may be revised as a result of experimental redetermination now in progress.

Consequently, it behooves the SMPTE and all other organizations concerned with the advancement of color television, color photography, and color reproduction in general to participate aggressively in the current activities and deliberations which will shortly lead to a decision by the CIE on this important matter.

Nearly a quarter of a century has elapsed since the (1931) adoption of the present CIE resolutions concerning colorimetry, on which are based all of the fundamental discussions of color reproduction by television. All of the delegates to the CIE are determined that this time the job shall be done so well that no further revisions will be necessary in the next quarter of a century. Therefore, the present is the last chance for us to make our voices heard and our influence felt.

In its own interest, as well as in the best long-term interest of all the color industries, the weighty and respected counsel of the SMPTE might appropriately be brought to bear favoring the redefinition of the luminosity data as a linear combination of directly determined color-mixture data. For that purpose, the best channels for comment and action are the Engineering Vice-President of the SMPTE, or our representatives on the U.S. National Committee of the CIE.

Discussion

W. T. Wintringham (Bell Telephone Laboratories): As the SMPTE representative on the National Committee, CIE, I'd be very glad to hear any opinions that the Society has. However, these are questions which I think Dr. MacAdam can help me on. Do Stiles' color-mixture data straighten out the troubles that Jacobsen and others have had in comparing colors?

Second, while heterochromatic photometry is difficult, it is possible to do something by flicker. Do figures obtained by use of the present luminosity curve look wrong or do they turn out to be wrong when flicker photometry is used?

And last, are the differences or inconsistencies between the two sets of data, the color-mixture functions and the luminosity function, are they real differences or might they be explained on the basis of different intensity levels at which the two sets of experiments were performed?

Dr. MacAdam: In response to the first question, a field test is now being organized by Dr. Judd, of the National Bureau of Standards, in accordance with one of the recommendations adopted at the Zürich meeting of the CIE. Judd is using Stiles' tentative data to prepare computation forms which will be circulated to all interested persons, to test with troublesome colors such as I described. Stiles' data seem to differ from the present CIE color-mixture functions in the manner required to eliminate the troubles.

In response to the second question, the changes proposed in the luminosity curve are rather small. They are embarrassing because the standard curve has been used so many years and because so many lamp output ratings would have to be changed. The most severe effects would be encountered with highly chromatic sources, for which heterochromatic photometry is highly unsatisfactory anyhow. Under ordinary circumstances of observation, I doubt if anyone would notice the differences resulting from the proposed revision of the luminosity curve. In the extreme cases, of highly chromatic sources, I think most people would agree that the effects of the proposed revision are in the right direction.

In response to the third question, differences between results for various observers are considerable, in both the luminosity curve and in the color-mixture curves. That's why we must have so many observers and take averages. But the adopted data also depend on the way in which the several groups of data are combined. The way that was adopted in 1931 was to juggle the color-mixture values to make them fit the standard luminosity curve. The result was to put the standard color-mixture curves outside the spread of experimental curves. This was not noticed, because the color-mixture curves were not completely determined in 1931. Stiles is now in the process of rectifying this incompleteness. The CIE now proposes to base the color standard on Stiles' final results, regardless of their relation to the standard luminosity curve. I think this is highly desirable, but want to point out that it will lead to trouble unless the luminosity curve is redefined as a linear combination of the new color-mixture curves. I am sure that the linear combination that best fits the experimental luminosity data will be well within the experimental spread of luminosity curves. When there is a choice of that sort, isn't it best to take the one which keeps everything within the spread of experimental data?

Now, concerning the luminosity data themselves, the original experimental work was done under quite different experimental conditions than are used in modern visual colorimetry. However, Sperling used the same apparatus and the same conditions of observation, in order to get comparable color-mixture functions and luminosity functions for each observer. Although his work is not yet complete, his preliminary results seemed conclusive: that no linear combination of the color-mixture data for an observer can fit the luminosity data of that observer within his experimental accuracy. Logically, then, we should discard the very idea of a luminosity curve, as futile. But as engineers we have to deal with light as energy, and need some spectral sensitivity curve with which to evaluate visual intensity. Therefore, we must choose an evaluating function arbitrarily, without hope of rigorous experimental justification. On the other hand, we can get valid color-mixture functions. Disagreement between color and luminosity evaluations of physically different but visually equivalent colors would be intolerable. Danger of such disagreements can be eliminated only by arbitrarily defining the standard luminosity data as a linear combination of the color-mixture data.*

* Footnote added in editing: This point of view is further elaborated by D. B. Judd in the Journal of the Optical Society of America for October, 1955, Vol. 45, page 897.

Progress Toward International Motion-Picture Standards

By D. R. WHITE

As Chairman of ASA Committee PH22 it has been my privilege to head the U.S. delegations to two meetings of the Technical Committee 36, Cinematography, of the International Standards Organization. The first of these was held at New York in 1952 and the second at Stockholm, Sweden, this past June.

I am convinced that there are genuine business values in these voluntary international activities just as there are business values in our own voluntary national standardization efforts. In both cases, compliance is termed voluntary but the meaning is different from country to country. In the U.S.A., voluntary compliance with a standard clearly means we are free to comply or not as we wish. A buyer who wishes to purchase goods in accord with a given standard can place that requirement in a purchase order and compliance then becomes a matter of contract. On the other hand, engineers can plan a new balance of picture area, soundtrack and perforation dimensions, and that new system can compete with older systems without the mere existence of older standards being a complete bar to progress.

There are countries where this description does not apply. In some cases standardization is considered a function of government. Compliance with a standard set up within a given country can become a matter of law; therefore in such a case the voluntary acceptance of an international proposal is then not an individual acceptance but is a national acceptance.

These differences in viewpoint and procedure enhance rather than lessen the importance of timeliness in standardization activities. If delayed too long, diverse proposals become law in different countries and agreement on any one proposal becomes very difficult. If started too early, the need is not sensed in all countries and there is a resulting lack of cooperation. Examples of each type could be cited from the Stockholm experience. I think, however, you can see the business value and importance of properly timed international standardizing activity.

The meeting in 1952 was the first meeting of its kind, and while significant work was accomplished, subsequent events showed opportunities for improvement in organization and handling of details that had kept the paper work slowed to a snail's pace. This was true even in areas where agreement appeared to have been reached at the meeting. Omitting the many details, suffice it to say that the organization of the 1955 meeting benefited from the 1952 experience and we hope and expect that follow-up work will proceed much more expeditiously.

Before proceeding with the detailed account of progress and status, I would like to outline to you recognized distinct steps of progress named and designated in ISO procedure.

A Draft ISO Proposal is a document prepared by the Secretariat of a Technical Committee and circulated for consideration by the members of that Committee. Typically, a date is set, and unless criticism is received before that date, approval is assumed for participating members. In case criticism is received which appears pertinent, the Secretariat can prepare 2d, 3d, 4th, . . . Draft ISO Proposals and circulate them until approval is indicated by a majority.

At this point, the document becomes a Draft ISO Recommendation and is submitted to the ISO General Secretariat, together with a résumé of the back-

Presented on October 3, 1955, at the Society's Convention at Lake Placid, N.Y., by D. R. White, Research Div., Photo Products Dept., E. I. du Pont de Nemours and Co., Inc., Parlin, N.J.
(This report was submitted on October 17, 1955.)

ground. The General Secretariat then circulates the Draft ISO Recommendation to all ISO member countries and again sets a closing date for action.

If a majority approves, a final report is prepared for review by the ISO Council which decides whether the Draft ISO Recommendation should be accepted as an ISO Recommendation. An ISO Recommendation so accepted can be a good and effective working basis for international business in the area covered.

Procedural steps also exist for the transformation of an ISO Recommendation into an ISO Standard by steps requiring unanimous agreement of all ISO member nations. No such ISO Standards exist as yet.

As a result of the New York meeting of 1952, 22 Draft ISO Proposals had been prepared and received the approvals necessary for the preparation of the corresponding Draft ISO Recommendations. Seven of these Draft ISO Recommendations were circulated early enough so that the period for their consideration had expired prior to the Stockholm meeting. In each case, the official U.S. position was "approval."

Fifteen were circulated for consideration shortly prior to the Stockholm meeting with the period for consideration by national bodies due to expire September 20, 1955. These fifteen were given further consideration at Stockholm with the following results:

Three were allowed to stand unchanged.

Nine were referred to the Secretariat for revision and re-submission.

Three were ordered withdrawn for consolidation with new material not ready in 1952.

The three which were allowed to stand unchanged were submitted to letter ballot of PH22. Additional suggestions for improvement were received and action has been taken to assure the opportunity for this.

The nine in which the Secretariat was instructed to make revisions will be submitted to letter ballot of PH22 when the new documents come through from the ISO General Secretariat, probably a few weeks from now.

The Stockholm meeting resulted in agreement on the technical content of eight items to be prepared and circulated as Draft ISO Proposals. These were:

Number	*Subject*
1	Film Dimensions (16mm)
1	Screen Luminance
4	Magnetic-Track Dimensions and Locations
1	Reproduction Characteristics of Magnetic Soundtracks
1	Maximum Image Ratio and Location for Projection of Wide-Screen Pictures From Normal-Format Images

Seven of these are in the hands of the Secretariat and one is to be worked out in conjunction with a Permanent Working Group, as they were called at Stockholm.

These Working Groups of ISO Technical Committee 36 were charged with carrying out limited specific responsibilities assigned to them. Their work is expected to result in presentation to the Secretariat of documents recommended for circulation as Draft ISO Proposals.

The Working Groups are composed of representatives of nations which appear to have primary interests in the specific area covered. Acting for the U.S.A., I requested representation on all Working Groups formed. There were seven such groups set up to work in the following areas:

Film Dimensions
Definition and Marking, Safety Film
Screen Luminance
Films With Magnetic Striping
Reproduction Characteristics (Magnetic)
Wide Screen Pictures
Image Areas (16 mm)

The men chosen to be the representatives of PH22 and, therefore, of the U.S.A. on the Permanent Working Groups are being instructed to:

1. Plan their work to agree with current activities of the appropriate Engineering Committee of the SMPTE and PH22, and seek Committee advice and guidance when necessary and desirable.

2. Clear policy matters with the Chairman of PH22.

3. Provide the Secretary of PH22 with copies of international correspondence.

Based on present experience, this will yield Draft ISO Proposals of good technical quality.

I believe you will recognize from this brief review the significant progress which is being made in international standardization in cinematography.

motion-picture standards

SMPTE Recommended Practice Approved

The proposed SMPTE Recommended Practice, Magnetic Coating of 16mm Magnetic-Photographic Sound Record, published in the May 1955 Journal for trial and comment, was approved without change by the Society's Board of Governors on October 2, 1955, at its quarterly meeting preceding the opening of the Society's 78th Convention at Lake Placid.

A copy of this Recommended Practice may be had without charge upon request directed to Henry Kogel, Staff Engineer, at Society headquarters.—*H.K.*

Revision of American Standard—PH22.34, Dimensions for 35mm Motion-Picture Negative Raw Stock

A proposed revision of American Standard Z22.34-1949 is published on the following page for a three-month period of trial and criticism. All comments should be sent to Henry Kogel, SMPTE Staff Engineer, prior to February 15, 1956. If no adverse comments are received, this proposal will then be submitted to ASA Sectional Committee PH22 for further processing as an American Standard.

The proposed revisions of this standard as approved by the Film Dimensions and Standards Committees are peripheral rather than fundamental in nature and consist of the following:

(1) Changes in the table of dimensions to make the dimension and its tolerance consistent.

(2) Modification of the method of indicating dimension G to be in accord with international practice and the other film dimension standards processed since 1952.

(3) Interchange of symbol F for I so that the dimensions will have an alphabetical sequence.

(4) Addition to the appendix of the concept that film may swell as well as shrink.

(5) Addition of note 5 to provide a cross reference to American Standard PH22.93–1953, Dimensions for 35mm Motion-Picture Short-Pitch Negative Film.

It is interesting to note that both in the previous review of this standard in 1948 and in the present review, proposals were made that the standard be withdrawn, although for entirely different reasons. As stated on page 358 of the March 1949 Journal, the question at that time was the difference between the 35mm negative and positive perforations and the hope that the development of a universal negative-positive perforation might replace the differing films and standards. This negative-positive perforation, based on an original proposal by Dubray and Howell, has come into existence and has been standardized in PH22.1–1953, Dimensions for 35mm Motion-Picture Film Alternate Standards for Either Positive or Negative Raw Stock. However, this has not replaced the need for the negative perforation.

Note 5 of the proposed standard provides the clue to the question today. PH22.93–1953, Dimensions for 35mm Motion-Picture Short-Pitch Negative Film, was developed to take into account the need to decrease the pitch of negative film to make allowance for the recent decrease in the shrinkage characteristics of film. This decrease in pitch prevents any relative slippage between the negative and positive film when a sprocket-type printer is employed. (The details of this story were published in the December 1952 Journal, page 527.) With the development of short-pitch negative film, there has been a constant shift in the proportion of negative film perforated according to PH22.34 and PH22.93 with an ever-increasing amount perforated to the specifications of the latter standard. The question raised in this period was, therefore, whether sufficient film is being perforated to PH22.34 specifications to justify the continuance of this standard. The answer to this was in the affirmative and consequently, the processing of this standard has been continued. However, it is considered unlikely that it will remain in force for any lengthy period.—*H.K.*

Proposed Alternate Standard for Positive Raw Stock

A Proposed American Standard, 35mm Motion-Picture Alternate Standard for Positive Raw Stock, PH22.102, is published here for a three-month period of trial and criticism. All comments should be sent to Henry Kogel, Staff Engineer, prior to February 15, 1956. If no adverse comments are received, the proposal will then be submitted to ASA Sectional Committee PH22 for further processing as an American Standard.

Late in April 1953, the 20th Century-Fox Film Corp. requested the cooperation of the Eastman Kodak Co. in the modification of release-print perforations to obtain more space for picture and four magnetic soundtracks on 35mm film for the CinemaScope process then in a stage of development. The present proposal is an outgrowth of the joint activities begun at that time.

The following considerations entered into the design of the new perforations and sprockets:

(1) Additional usable area could be gained by decreasing the width of the perforation, dimension C, in American Standard Z22.36–1947 (now PH22.36–1954) and moving the perforations and sprocket teeth away from the center of the film by increasing dimension I in PH22.36 (dimension F in this proposal).

(2) The sprockets must give satisfactory wear with the existing release-print perforations as specified in PH22.36, Dimensions for 35mm Motion-Picture Positive Raw Stock.

(3) The sprocket teeth must be enough smaller than the flat portion of the perforation to permit film having a shrinkage range of 0 to 0.6% to run on the sprockets satisfactorily.

(4) Enough tolerance in the width of the hole must be allowed to permit a weave of 0.002 in. in the film without having the sprocket teeth come in contact with the rounded portion of the sprocket hole.

(5) It was believed from earlier test data that if the intermittent sprocket diameter were increased to 0.953 in. from the 0.935–0.953 in. range found in commercial practice, the decrease in wear on the film obtained by using the theoretically better sprocket diameter would offset any possible increase in wear that might be caused by the narrow teeth.

The special considerations involved in the use of release-print films with differing perforations are outlined in Appendix 2 and 3 of the proposal.

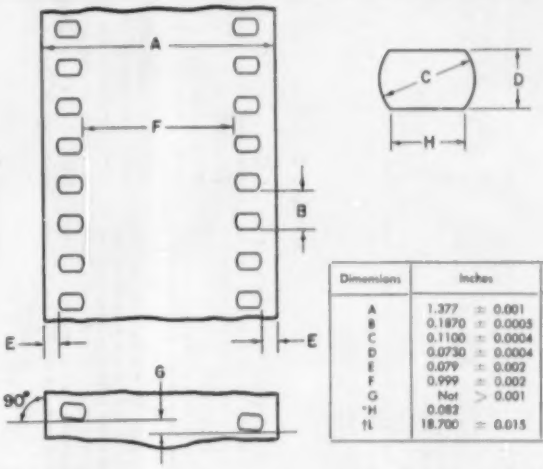
This proposal has been approved by the Film Dimensions and Standards Committees.—*H.K.*

Proposed American Standard

Dimensions For 35mm Motion-Picture Negative Raw Stock

PH22.34

Rev. Z22.34-1949



Dimensions	Inches	Millimeters
A	1.377 ± 0.001	34.98 ± 0.03
B	0.1870 ± 0.0005	4.750 ± 0.013
C	0.1100 ± 0.0004	2.794 ± 0.010
D	0.0730 ± 0.0004	1.854 ± 0.010
E	0.079 ± 0.002	2.01 ± 0.05
F	0.999 ± 0.002	25.37 ± 0.05
G	Not > 0.001	Not > 0.025
*H	0.082	2.08
†L	18.700 ± 0.015	474.98 ± 0.38

These dimensions and tolerances apply to the material immediately after cutting and perforating.

NOTE:

1. This film is used for motion-picture negatives and certain special processes.
2. Method of indicating dimension G is the main change from Z22.34-1949.
3. *A calculated value for a dimension not measured routinely in production.
4. †This dimension represents the length of any 100 consecutive perforation intervals.
5. This standard differs from American Standard PH22.93-1953, Dimensions For 35mm Motion-Picture Short-Pitch Negative Film, only in the values of B and L.

APPENDIX

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but since film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the slitters, punches and dies. Film can shrink or swell due to loss or gain in moisture content or can shrink due to loss of solvent. These changes invariably result in changes in the dimensions during the life of the film. The change is generally uniform throughout a roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness.

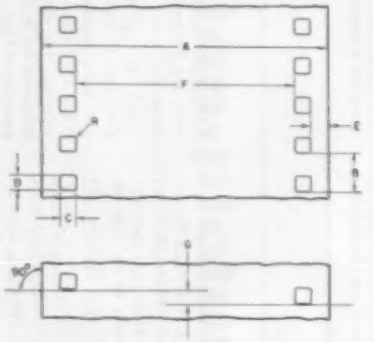
Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important.

NOT APPROVED

Proposed American Standard

Dimensions For 35mm Motion-Picture Film Alternate Standard For Positive Raw Stock

PH22.102



Dimensions	Inches	Millimeters
A	1.377 ± 0.001	34.98 ± 0.03
B	0.1870 ± 0.0005	4.750 ± 0.013
C	0.0780 ± 0.0004	1.981 ± 0.010
D	0.0730 ± 0.0004	1.854 ± 0.010
E	0.086 ± 0.002	2.18 ± 0.05
F	1.049 ± 0.002	26.64 ± 0.05
G	Not > 0.001	Not > 0.025
*L	18.700 ± 0.015	474.98 ± 0.38
R	0.013	0.33

These dimensions and tolerances apply to the material immediately after cutting and perforating.

NOTE:

1. This film is used for special process motion-picture prints (see Appendix 2 and 3).
*2. The L dimension represents the length of any 100 consecutive perforation intervals.
3. The millimeter dimensions are conversions from the inch dimensions and "rounded off" as per American Standard B48.1-1933 which was reaffirmed in 1947.

NOT APPROVED

APPENDIX 1

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but since film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the slitters, punches and dies. Film can shrink or swell due to loss or grain in moisture content or can shrink due to loss of solvent. These changes invariably result in changes in the dimensions during the life of the film. The change is generally uniform throughout a roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness of projection.

Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important.

APPENDIX 2

It should be particularly noted that film made to this standard will not fit over pins and sprocket teeth designed to fit film perforated to American Standards PH22.36-1954, PH22.1-1953, PH22.93-1953 or Z22.34-1949. The perforation hole size shown on the above listed American Standards is 0.073 x 0.110 in. except for PH22.36-1954 which has 0.078 x 0.110-in. holes, whereas, for this new standard, the hole size is 0.073 x 0.078 in. Films with holes of this size would be injured at the perforation edges when run on standard sprockets or pins carried by most 35mm film-handling apparatus. New or modified sprockets and pins designed to accept the 0.073 x 0.078-in. hole, however, can be used in conjunction with film perforated to the other existing 35mm motion-picture film standards.

The wear life of film perforated in this manner should be nearly equal to that of film having other standard perforations. Experience has shown, however, that the wear life obtained with these perforations, as well as that obtained with other standard types of perforations, can be greatly extended by the use of intermittent sprockets having a base diameter of 0.950 to 0.935 in. in place of sprockets of lesser diameter.

APPENDIX 3

Most 35mm motion-picture films produced prior to 1954 were perforated with two rows of perforations, each perforation being 0.110 x 0.078 in. for positive film and/or 0.110 x 0.073 in. for negative film. Such film, in addition to carrying the picture, accommodates a single soundtrack between one row of perforations and the picture frame. The desire to reproduce multichannel sound on the same film that carries the picture image, and yet not reduce the image size, led to the use of smaller perforations, on positive film. Films perforated to this smaller perforation standard have wider margins (dimension E) and wider usable film areas between the rows of perforations than that for other positive film perforated to American Standards PH22.36-1954 and PH22.1-1953. This permits the placement of a magnetic coating for the multichannel sound record along both edges just outside the perforations and along both sides of the picture just inside the perforations.

NOT APPROVED

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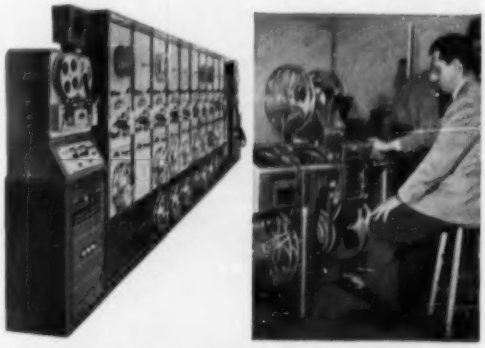


AT LEFT: Lineup of dubbing machines and dubbing recorder. Re-recorded version is 6-track stereophonic sound on 35mm magnetic film. AT RIGHT: Westrex Editer—with 70mm film in the picture gate, and two 35mm sound films, one in the regular gate and one in the special sound head attachment.

news and reports

79th Convention, New York

A tentative format has been organized by Ben Plakun, Program Chairman, on the basis of ideas assembled chiefly at the Papers Committee meeting at Lake Placid, October 5.

Subject to many small changes right up to Convention time — April 30 — the technical sessions will start off with laboratory practice papers all day Monday, followed by consideration of miscellaneous film sizes on Monday evening. Tuesday will have sessions covering motion-picture production, projection and viewing and some somewhat popular papers on television and high-speed photography in the evening. Television in general, but studio lighting in particular, will comprise concurrent sessions with high-speed photography on Wednesday. Thursday and Friday sessions will cover screen brightness and sound, chiefly sound recording.

Television Studio Lighting

Hank Gurin, and his SMPTE TV Studio Lighting Committee, have been planning an extensive Studio Lighting Symposium. Hank says:

"Do you have a problem in TV studio lighting? Or have you found a solution to any particular difficulties about which you can tell others? These sessions will stress transition from black-and-white to color.

"The TV Studio Lighting Committee is inviting all those interested to submit technical papers or to take part in a panel discussion to be held after the papers are presented. Broadcasters and equipment manufacturers are urged to participate."

Those wishing to take part should send title of their subject and brief abstract to:

H. M. Gurin, Chairman
SMPTE TV Studio Lighting Committee
55 W. 42 St. (Room 1004)
New York 36

Equipment Exhibits

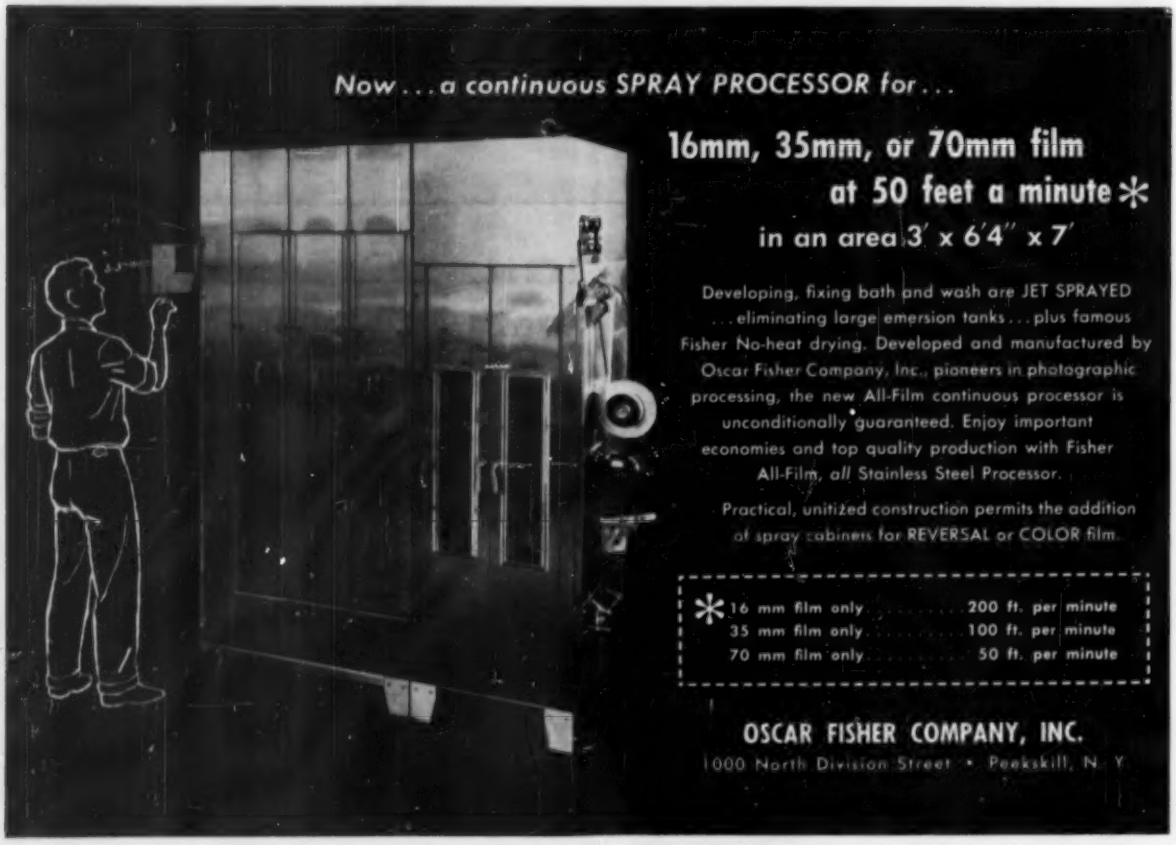
The Spring Convention will have exhibits. In October a brochure with floor plans was sent to the Society's Sustaining Members and to others possibly interested. More than half the space has already been contracted for. All Convention registrants and guests of exhibitors will have passes to visit the exhibit area in the Penn Top South in New York's Statler. The public will not be admitted. Full information is available from:

Everett Miller, Exhibit Chairman
RCA Film Recording
411 Fifth Ave.
New York 16

Papers Program Planning

Until the complete roster of Subject Chairmen for the Convention is announced, inquiries or suggestions about technical papers should go to Papers Committee members (p. 197, April 1955 *Journal*) or to:

Bernard D. Plakun, SMPTE Program Chairman
General Precision Laboratory Inc.
Pleasantville, N.Y.


Now . . . a continuous SPRAY PROCESSOR for . . .
16mm, 35mm, or 70mm film
at 50 feet a minute *
in an area 3′ x 6′4″ x 7′
Developing, fixing bath and wash are JET SPRAYED . . . eliminating large emersion tanks . . . plus famous Fisher No-heat drying. Developed and manufactured by Oscar Fisher Company, Inc., pioneers in photographic processing, the new All-Film continuous processor is unconditionally guaranteed. Enjoy important economies and top quality production with Fisher All-Film, all Stainless Steel Processor.
Practical, unitized construction permits the addition of spray cabinets for REVERSAL or COLOR film.
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35 mm film only . . . 100 ft. per minute
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Report on Lake Placid Convention

The 78th convention proved highly successful, surpassing all expectations. Total attendance was about 450, compared with the 218 who attended the last Lake Placid convention in 1950. Member weekly registration totalled 236; member daily registration, 31; ladies registration, 125; and nonmember registration, 58. One-hundred and five members and 61 ladies took advantage of the time-saving method of advance registration initiated at the 77th Convention in Chicago last Spring.

The 78th papers program featured the theme "Color in Motion Pictures and Television." Organized by Glenn Matthews, it consisted of 57 technical papers, divided into 12 sessions on materials and standards, studio practice, projection and viewing, laboratory practice, television practice, high-speed photography, educational TV and television equipment, and television and sound.

To distribute the burden of detail work and permit more careful review of proposed papers, Glenn was assisted by Gordon Chambers, in charge of the Laboratory Practice sessions; John Stott, who coordinated papers on Materials and Standards; Charles Daily, in charge of Projection and Viewing sessions; Fred Kolb, coordinator for the roundtable on Projection for the Large Screen; Gentry Veal, in charge of the Television Practice Sessions; Petro Vlahos, in charge of the Studio Practice session; and John Waddell, in charge of the High-Speed Photography sessions.

The technical papers included two from Tokyo, two from Germany and three from Canada. For the first time, a small session was arranged on educational television with the purpose of acquainting our members with activities in this rapidly growing field.

An innovation on the technical program was three roundtable discussions on important subjects of high current interest to the motion-picture and television industries — Motion-Picture Studio Production Problems; Projection for the Wide Screen; and Problems of Network Broadcasting in Monochrome and Color. Each of the roundtables consisted of a panel of four or more experts who presented their views on the subject under discussion and then answered a lively barrage of questions from the floor. Chairmen of the panel discussions were Norwood Simmons, Fred Kolb and Gentry Veal.

The complete roster of papers as finally presented will appear in the December *Journal*. The high quality of the technical sessions will be reflected in forthcoming *Journals* when the papers and discussions which followed them are published.

Credit for the quality and smoothness of the convention is due Byron Roudabush, Convention Vice-President, Don Hyndman, Local Arrangements Chairman, and their able team of committee chairmen. All did an excellent job despite the fact that advance arrangements had to be handled at a distance from Lake Placid.

The difficult and demanding job of registration was directed by Jim Naughton, who was assisted by Bill Westphal in the auditing department, and Marie Lucas. Even the lengthy lines that formed early Monday morning didn't ruffle the calm of this able group, which handled their tasks smoothly and efficiently.

Hotel Arrangements were the province of Lou Feldman, who handled these tasks with dispatch and even found time to be of assistance in other areas.

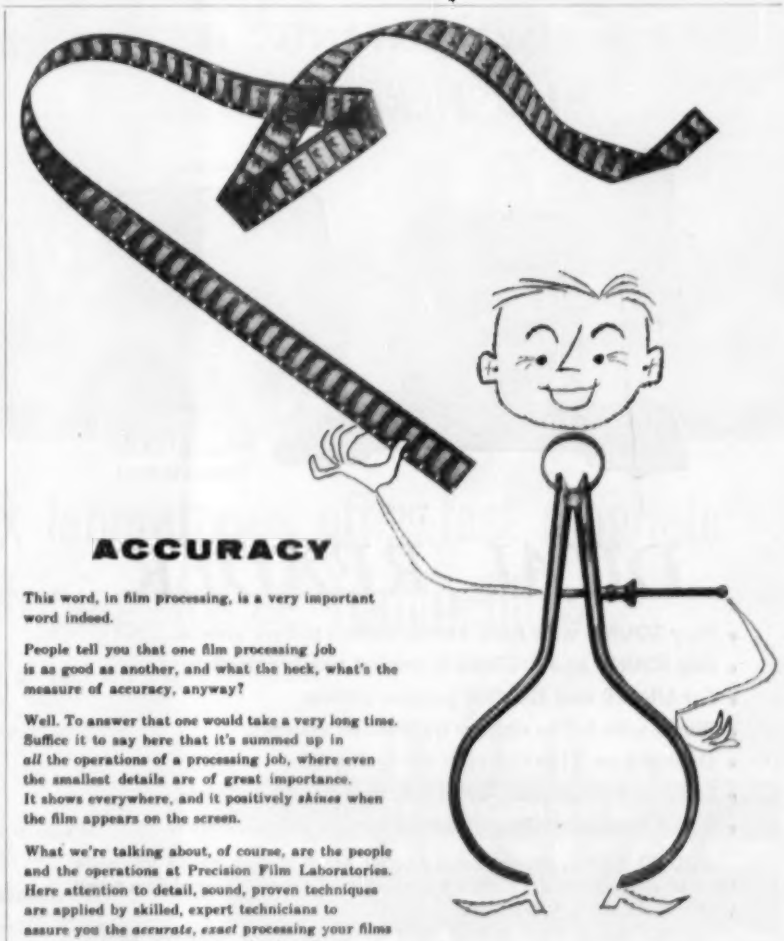
Another man of all work was Administrative Assistant Bill Metzger who willingly lent a hand wherever needed.

The cordial dispenser of hospitality, and general information about local tourist attractions, was Gar Misener. His Hospitality Desk and the neighboring Membership Desk manned by Joe Aiken provided daily service to convention registrants. Joe snared six new Society members and did a thriving business in membership pins as well.

The complex projection chores were directed by Bill Hecht and Jim Moses; and activities in the public address and recording departments were the responsibility of Jack Leahy. For their virtually twenty-four hour a day jobs, they deserve special thanks.

Up-to-the-minute printed word of what was transpiring went to the outside world via the typewriter of Sue Grotta, who handled publicity.

For the extensive and enjoyable entertainment program in which everyone readily took part, thanks are due to Reid Ray, Entertainment Chairman, Earl Spon-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able and Frank Cahill. Their program was unusual and original, and its informality provided excellent opportunities for members to get to know each other better. Golf activities were handled by Bunny Hanson.

Last but certainly not least were the ladies. Their committee was headed by Oscar Neu with Mrs. Hyndman and Mrs. Sponable serving ably and graciously as cohostesses.

The Annual Awards session, the full text of which will appear in the December *Journal*, was arranged and directed by John Stott. Through his efforts the program was interesting and dignified, in keeping with the importance of this annual occasion at which the Society formally recognizes the technical accomplishments of members of the industry. John also served as Chairman of the Banquet Committee.

The "Camera Trails Along Nature Trails" illustrated lecture by Dick and Ada Bird was one of the more rewarding and interesting experiences of the convention. In addition to the excellent color motion pictures of bird and small animal life in the United States and Canada, those attending were charmed by the dry wit and humor of Mr. Bird's interesting account of his experiences.

Bird, a former newsreel cameraman of nearly 50 years experience, and Ada, his pretty brunette wife and assistant photographer, have worked in a remote area of the Canadian Rockies several months each summer for five years making shots for the Disney picture *Arctic Wilderness*, scheduled for release in 1956. Each of these intrepid photographers has infinite patience, insatiable curiosity to search out their quarry, and great skill to record the scene and action on Kodachrome film.

The Birds use only their original color film for their lectures and many who saw their motion pictures expressed amazement at the freedom from scratches and dirt of the film. They were even more impressed when Dick told them after the lecture that some of the sequences of this film had been projected more than 1000 times. Ada always rewinds and wipes the film after each showing and maintains the projector in first-class condition.

In addition to showing their pictures to groups all over this country and Canada, these two nature photographers preach conservation at every opportunity, pointing out that the birds destroy countless insects that would otherwise do considerable damage to crops.

When working in the field, most of their shots are made without the use of blinds by remaining long hours in the area until the bird or animal they want to photograph becomes accustomed to them. Dick dislikes rehearsed shots and prefers to photograph nature as he finds it.

During the convention 12 engineering committee meetings were held. There were also the 79th Convention Papers Meeting and the meetings for 79th and 80th Convention Arrangements. *S.G.*

Society Election

The 1955 national SMPTE election ballots were counted on October 2, and the results of the election were reported to the membership at the Annual Meeting held on October 3 during the 78th semiannual convention at the Lake Placid Club, Essex County, N.Y. The following national officers and governors were re-elected for two-year terms beginning January 1, 1956:

John W. Servies, Financial Vice-President
Axel G. Jensen, Engineering Vice-President
Geo. W. Colburn, Treasurer
Frank N. Gillette, Governor, East
Garland C. Misener, Governor, East
Richard O. Painter, Governor, Central
Reid H. Ray, Governor, Central
Lorin D. Grignon, Governor, West
Ralph E. Lovell, Governor, West

President Frayne announced that the Board of Governors had accepted with regret the resignation of Secretary Edward S. Seeley whose move to the West Coast and new duties were described in the September *Journal*. Wilton R. Holm was appointed to fill the remainder of the Secretary's term, through December 31, 1956.

The following section officers and managers were elected — the Chairmen and Secretary-Treasurers for one-year terms, the Managers for two. By virtue of their offices the three section chairmen also serve one-year terms as Society Governors.

Atlantic Coast Section
George H. Gordon, Chairman
Victor M. Salter, Secretary-Treasurer
Albert A. Duryea, Manager
Robert M. Fraser, Manager

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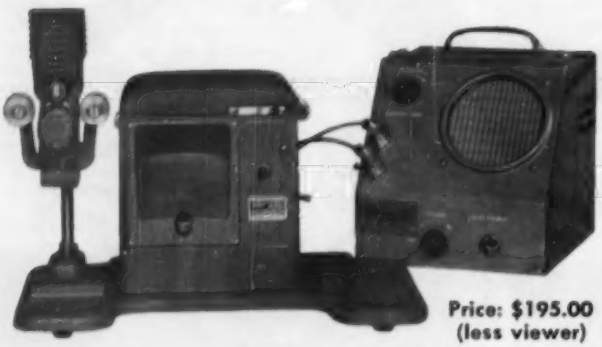

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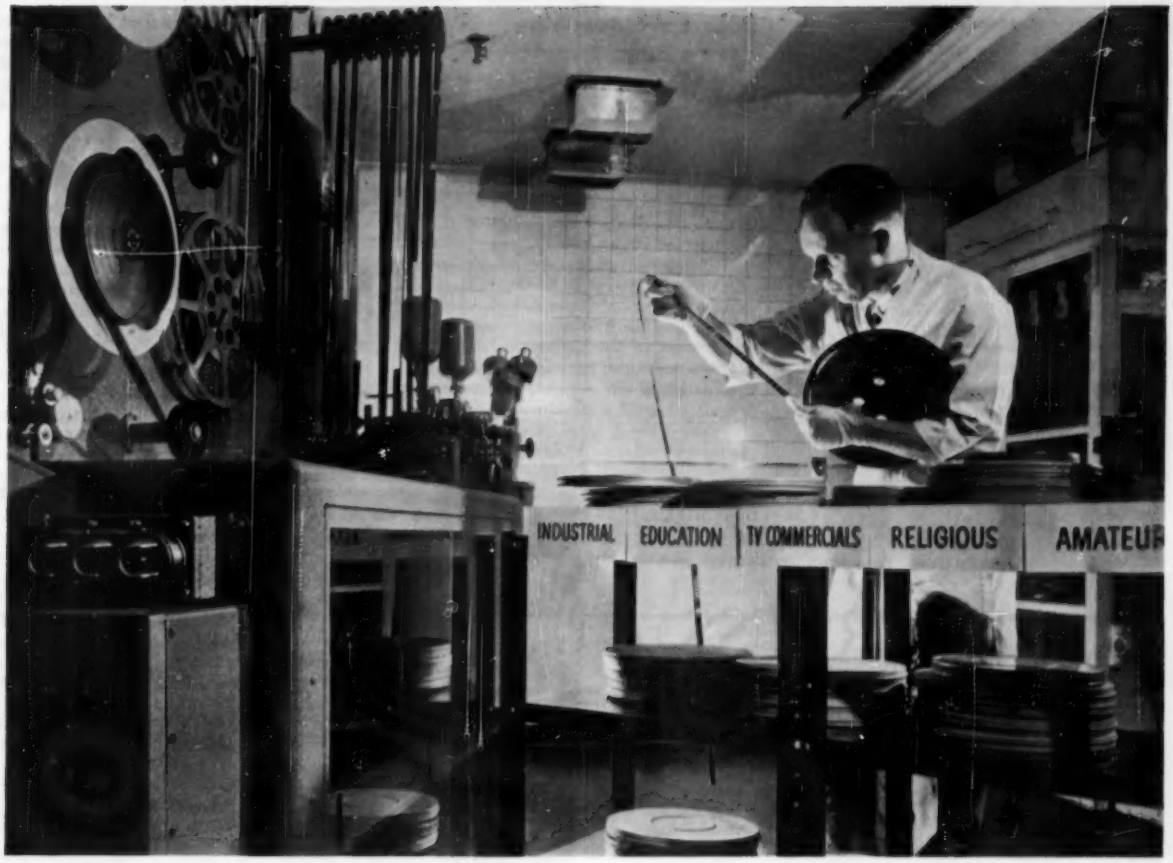

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(Saul Jeffee has been appointed to fill the unexpired term of Victor M. Salter who was on the Board of Managers and was elected Secretary-Treasurer.)

Central Section
Kenneth M. Mason, Chairman
Howard H. Brauer, Secretary-Treasurer
Robert E. Colburn, Manager
Philip E. Smith, Manager
(A tie for the third Managership was unresolved at the time of printing. The outcome will be reported in a later issue of the *Journal*.)

Pacific Coast Section
Edwin W. Templin, Chairman
John W. DuVall, Secretary-Treasurer
Merle H. Chamberlin, Manager
G. Carleton Hunt, Manager
Cameron G. Pierce, Manager

Board of Governors

The fourth meeting for 1955 of the Society's Board of Governors was held on October 2 at the Lake Placid Club, Essex County, New York. As usual the Board met at the close of the third quarter to review operations for the year and to plan the scale of activities to be conducted through 1956.

The Board discussed extensively the question of resort conventions and concluded that conventions should not be held at resorts so often as to become a hardship to a large portion of the membership, nor to make it difficult to introduce new people to the work of the Society. In some cases expenses are a problem and daily registration falls off in isolated locations. At present we hold approximately one resort convention every three years; the next is planned for May of 1959 in Miami Beach.

The Board also received, but delayed acting upon, a suggestion that at some time in the future conventions be scheduled from midweek to midweek, thus allowing members' families to take advantage of reduced transportation rates.

John W. Servies, Financial Vice-President, reported on the present state of fiscal affairs and presented budget recommendations for 1956 for Board approval. Included in this plan for continued growth of the Society are the following recommendations approved by the Board for adoption in 1956: purchase by the Society of an Addressograph membership record system, specifically designed for the needs of SMPTE — this system to facilitate the Society's ability to service its growing membership efficiently and accurately; adoption of a program of publicity-public relations aimed at informing members of Society activities through monthly newsletter-section meeting notices and through brief items in the *Journal*, and introducing others to what we are doing through releases to the trade and daily press; publication of the Color Committee's treatise on "Elements of Color in Professional Motion Pictures"; publication of a 40-year *Journal* index; introduction of a standards binder service to be available as soon as internal controls are developed; and installation of air conditioning at Society Headquarters.

Publication of American Standard "Screen Brightness for 16mm Laboratory Review Rooms" and SMPTE Recommended Practice "Magnetic and Photographic Sound on 16mm Film With Perforations Along One Edge" was authorized by the Board.

Norwood L. Simmons, Editorial Vice-President, reported that the first meeting of the newly formed Publications Advisory Committee would be held during the 78th convention. Members of that group are: F. T. Bowditch, Glenn L. Dimmick, Lloyd T. Goldsmith, Ralph E. Lovell, Glenn E. Matthews, Pierre Mertz and Lloyd Thompson. Dr. Simmons also noted that Lloyd Thompson had been appointed Progress Committee Chairman for 1956.

President Frayne reported that Edward S. Seeley, who had recently moved from New York to Hollywood, would be unable to carry a heavy load of Society work and so had submitted his resignation as Secretary of the Society. It was proposed that Wilton R. Holm be appointed to fill the unexpired portion of Mr. Seeley's term. The Board accepted the changes and recommended that Mr. Seeley "be accorded the highest commendation for his years of careful and untiring work in discharging the parliamentary and other responsibilities of the office of Secretary."

Frank N. Gillette, Chairman of the Committee on Membership Requirements, reported that his committee had examined carefully the present membership requirements and admissions policies of the Society to determine if they presented any danger in regard to possible reduction in the professional caliber of Society membership. It was the conclusion of this group, approved by the Board, that the present system appears to be successful and that if care is taken by Membership and Admissions Committee members in the

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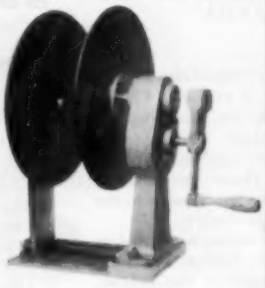
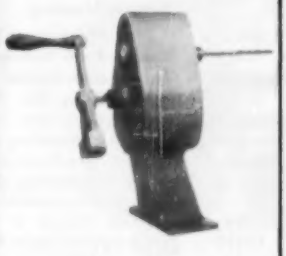


negative rewind set



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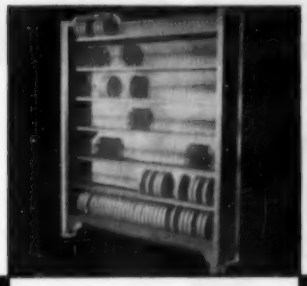

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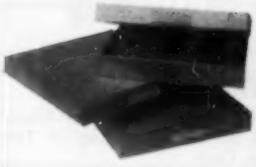
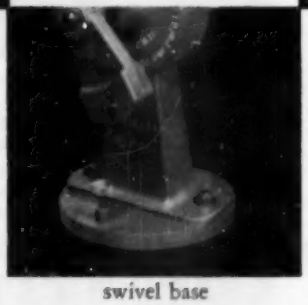


vault cans



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conduct of their duties that "there should be no difficulty whatever with undue dilution of quality of our voting membership."

President Frayne reported on the initial tangible results of the Education Committee's program. Three professional courses of instruction are now being offered through the Los Angeles Extension Division of the University of California in "Illumination Optics," "Duplication of Color Motion Pictures," and "Motion Picture Laboratory Practice."

A report of the activities of the Membership Committee, submitted to the Board by John W. DuVall, National Membership Chairman, indicated that 702 new members had been admitted to the Society during 1955 to September 23. This brings total net membership to 5,412.

Annual Meeting

The 1955 Annual Meeting of the Society was held on October 3 at Lake Placid. Three amendments to the Constitution, published in the August 1955 *Journal*, p. 448, were read and explained to the members attending. These amendments will now be submitted by letter ballot to the voting membership of the Society.

Because a quorum of voting membership was not present at the Annual Meeting, ten proposed amendments to the Bylaws, also published in the August *Journal*, were referred to the Board for final action and were passed, effective October 3.

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section reports

The regular **September technical session of the Pacific Coast Section** was held in Hollywood at the National Broadcasting Company's recently converted Studio A. There were 220 members attending.

Frank J. Somers, Television Maintenance Supervisor at NBC, Hollywood, presented a discussion of the architectural and electrical changes which had been made to convert Studio A for television film production. The Groucho Marx show is one of the productions regularly made there.

Sid Solow, Manager of Consolidated Film Industries, Hollywood, discussed, "Making 16mm Eastman Color Prints From a Kodachrome Original Using 35mm Eastman Color Camera Negative as an Intermediate." This was based on his paper which was so well received at the SMPTE Convention in Chicago in April 1955.

Jack L. Copeland, President of Copeland & Associates, Los Angeles, showed a prize-winning film, *Eye to the Unknown*, which was produced by his organization. The film described a new method of high-speed chemical analysis — mass spectrometry.

The officers and program committee of the Pacific Coast Section greatly appreciate the courtesy of Thomas W. Sarnoff, NBC, Hollywood, in making the studio and facilities available for this meeting, and also are grateful to Ralph E. Lovell of NBC for his cooperation in making the necessary studio arrangements.

The regular **October technical session of the Pacific Coast Section** was held at the American Broadcasting Company, Hollywood, Studio A, on Tuesday, October 18. A total of 205 members and guests attended.

The program consisted of four papers which had been presented at the 78th Semiannual Convention, Lake Placid, two weeks earlier. The papers, which all dealt with high-speed photography, were:

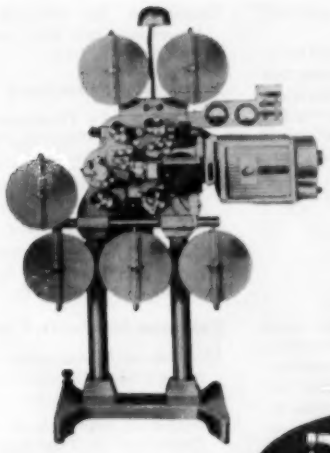
"The Iconolog — A Semiautomatic XY Coordinate Film-Reading Device for Recording and Tabulation of Data in Decimal-Digital Form," by Ralph E. Brown of Genisco, Inc.

"Data Reduction Equipment," presented by Robert Hill of Coleman Engineering Co.

"A New Film Reading Machine of Rather Unusual Versatility," by Bernard S. Benson of Benson-Lehner Corp.

"Data Reduction From High Speed Films," presented by Mr. Woodring of Telecomputing Corp.

The Section appreciates the cooperation of Cameron Pierce, Chief Engineer, Western Div., ABC, for his courtesy in making arrangements for the use of the ABC studio and facilities.—*E. W. Templin*, Secretary-Treasurer, Pacific Coast Section, % Westrex Corp., 6601 Romaine St., Hollywood 38.



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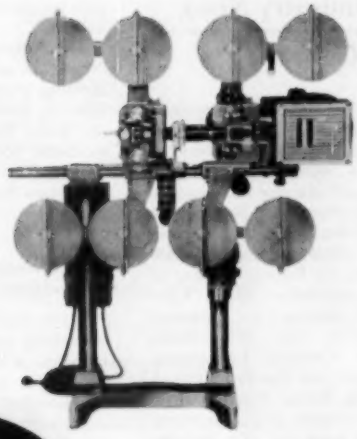

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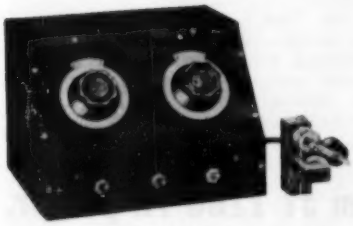

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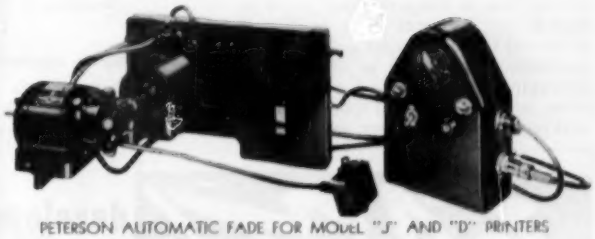

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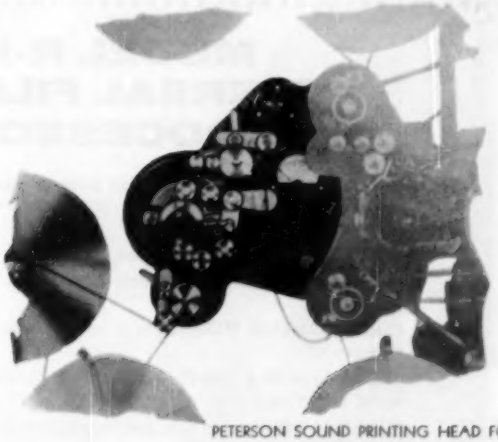

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Education, Industry News

Association of Cinema Labs Meeting

Progress made toward standardization of 16mm laboratory procedures, nomenclature and also the development of improved customer relations were reported at the Association of Cinema Laboratories meeting at Lake Placid on October 6. The Association heard three industry committees make recommendations: Nomenclature headed by Russell Holslag of Precision Film Laboratories, N.Y., Vice-President of the Association; Customer Relations, headed by Geo. W. Colburn of the Geo. W. Colburn Laboratory, Chicago, Treasurer; and Pre-Print Preparation, headed by Byron Roudabush of Byron, Inc., Washington, D.C., Secretary.

The Association grew out of a meeting of representatives of six film laboratories held in October 1952 during the SMPTE's 72d Convention in Washington, D.C. Its membership is now made up of 31 16mm film laboratories. Its initial organization and early efforts were described in the *Journal* for January 1954 by John Stott.

"A Report From the Association of Cinema Laboratories," in the July 1955 *Journal*, was a comprehensive paper by Neal Keehn, President of the Association. It covered the more recent activities of the Association, its relation to SMPTE, and laboratory procedures for A & B roll dissolves, laps, checkerboard splices, marking workprints to indicate effects and exposures, and preparation of printing head and tail leaders.

The Association's next meeting will be in New York on January 26 and a subsequent meeting is planned for Tuesday morning, May 1, during the SMPTE Convention in New York. Further information is available from the Association's Secretary, Byron Roudabush, Byron, Inc., 1226 Wisconsin Ave., Washington 7, D.C.

Still Photography and Television Standards

Below are listed the numbers and titles of recently approved American Standards in fields of interest to SMPTE members. Additional listings of such standards will be published in the *Journal* from time to time, as they are made available. Previous enumerations appeared in the July 1953 *Journal*, p. 82; in the January 1954 *Journal*, p. 91; and in the April 1955 *Journal*, p. 220. Indexes and copies of standards are available from the American Standards Association, Inc., 70 E. 45 St., New York 17.

Photographic Sensitometry, PH2

Photographic Exposure Computer, PH2.7-1955 (Revision of Z38.2.2–1949), $1.50.

Photographic Apparatus, PH3

Distance Scales for Focusing Camera Lenses, PH3.20-1955 (Revision of Z38.4.3-1947 and Z38.4.13-1948), 25¢.

Dimensions for Medical X-Ray Film Cassettes (Inch and Centimeter Sizes), Ph3.21-1955, 25¢.

Photographic Processing, PH4

Specification for Photographic Grade Hydroquinone, PH4.126-1955 (Revision of Z38.8.200-1949), 35¢.

Specification for Photographic Grade Potassium Bromide, PH4.200-1955 (Revision of Z38.8.204-1948), 25¢.

Index of American Standard and Proposed American Standard Specifications for Photographic Grade Chemicals, gratis.

Television Standards, C16

Methods of Measurement of Interference of Television Receivers in the Range of 300 to 10,000 KC, 60¢.

Methods of Aspect Ratio and Geometric Distortion of Television Cameras and Picture Monitors, C16.25-1955, 60¢.

Robert W. Clark has purchased the assets of the Rayco Electronic Mfg. Co. located at 11116 Cumpston St., North Hollywood, Calif. The company specializes in toroidal products, design, engineering and production of electronic components and also manufactures toroid winding machines for sale or lease.

Mr Clark has previously been engaged in television development work with the National Broadcasting Co. and most recently with the Lane Wells Co. William V. Mosher continues as Chief Engineer of the Rayco firm.

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current literature

The Editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D.C., or from the New York Public Library, New York, N.Y., at prevailing rates.

American Cinematographer vol. 36, Aug. 1955

The New Yellow Flame Carbons (p. 464) *C. Handley*
Set Lighting for Commercial Films (p.467) *C. Loring*
Eleven Cameras for Circarama (p. 476) *L. Allen*
New Automatic Shifting Shutter on Kodascope Pageants (p. 490)

vol. 36, Sept. 1955

Exposure Determination for Variable Shutter Speeds (p. 524) *F. P. Fritz*
Pre-printing Preparation of 16mm Film (p. 531)
Innovations Highlight New S6 Magnetic Recorder (p. 536) *F. Foster*

Bild und Ton vol. 8, No. 7, July 1955

Cinemascope—der neue Breitwandfilm (p. 182)
Neuere Xenon-Lampen für Farbaufnahmen und für Projektion (p. 184) *U. Kopec*

vol. 8, No. 8, Aug. 1955

Stereofonie und Tonfilm Pt. 2 (p. 210) *F. Sieland*
Neuere Xenon-Lampen für Farbaufnahmen und für Projektion (p. 213) *U. Kopec*
Uber die Zusammenarbeit von Kameramann und Kopieranstalt Pt. 2. (p. 215) *H. Mehnert*
Grundlagen der fotomechanischen Farbkorrektur (p. 217) *E. Rupp*
Gedanken über Automatisierung in der Vorführtechnik (p. 229) *K. Poser*

vol. 8, Sept. 1955

Über einige Grundfragen der elektroakustischen Musikübertragung (p. 244) *S. Mittlacher*
Über das Streulicht im Lichtspieltheater (p. 249) *H. Schering*
Wie soll man filmen?—88 Ratschlage für den 8-mm-Schmalfilmer (p. 255) *P. Sbrzesny*

British Kinematography

vol. 27, No. 2, Aug. 1955

Radar Cinematography (p. 34) *J. R. F. Stewart*
Modern Cine Camera Lenses (p. 37) *G. H. Cook*

vol. 27, Sept. 1955

Film Characteristics for Television Scanning Pt. I. Flying Spot Scanners (p. 73) *T. C. Nuttall*

Electrochemical Society, Journal

vol. 102, Sept. 1955

Two Photoelectric Colorimeters for Television Picture Tubes (p. 512) *R. S. Hunter*

Film Technikum vol. 6, No. 8, Aug. 1955

Neue Typen von Schmalfilm-Projektoren (p. 225)
Das neue Bolex-Programm (p. 228)
Ton-Probleme beim 8-mm-Schmalfilm (p. 230)
Vorsätze zur Bauer-88-B (p. 232)
Schneider-Objektive für Kinokameras (p. 233)
Ton-Schmalfilm-Projektor–Jungstram BM 2005C (p. 234)

Tonfilm-Kamera Auricon-Pro 600 Modell CM 75 (p. 236)
Das Movikon System im 8-mm-Film (p. 238) *D. B. Sasse*
Wohin steuert der Stereofilm (p. 240) *W. Selle*

Ideal Kinema vol. 21, Sept. 8, 1955

No Side Masking with the Supalex (p. 9)

Institute of Radio Engineers, Proceedings vol. 43, Aug. 1955

Color Television Luminance Detail Rendition (p. 918) *W. G. Gibson and A. C. Schroeder*
A New High-Efficiency Parallax Mask Color Tube (p. 936) *M. E. Amdursky*
Design of Lens-Mask Three-Gun Color Television Tubes (p. 943) *R. C. Hergenrother*

International Projectionist vol. 30, Aug. 1955

Recent Developments in Anamorphotic Systems (p. 8) *G. H. Cook*
Prevention of Damage to Prints (p. 15) *R. A. Mitchell*
New Yellow-Flame Carbons Increase Depth, Sharpness in Photographic Image (p. 20) *C. Handley*
SMPTE Color TV Test Films (p. 24)

International Projectionist vol. 30, Sept. 1955

Recent Trends in Shutter Design for Theatre and TV Projection (p. 7) *R. A. Mitchell*
Circarama: Spectacular 16-mm Presentation at Disneyland (p. 10)
A Stereophonic Sound System that Utilizes Haas Effect (p. 12) *B. P. Bogert*
Versatile New Simplex Sound Systems (p. 14)
Recent Developments in Anamorphotic Systems (p. 15) *G. H. Cook*

Kino-Technik vol. 9, Aug. 1955

Der Werdegang eines modernen Schmalfilmobjektives (p. 273) *Dr. Naumann*
Aus der Geschichte der Kinematographie Teil IV. (p. 286)

vol. 9, Sept. 1955

Lichttechnik im Filmatelier. Strombedarf und Stromversorgung (p. 306) *H. Orlich*
Die Stromversorgungsanlagen der Bavaria-Filmkunst (p. 308) *K. Neitzel*
Beleuchtungsprobleme in der Praxis des Kameramannes (p. 311) *F. Lehmann*
Stand der Beleuchtungstechnik bei Farbfilmaufnahmen (p. 312) *F. Krautschneider*
Sonderglühlampen für Filmscheinwerfer und Projektion (p. 314) *F. Ernst*
Vom Sonnenlicht zu den modernsten Kunstlichtquellen (p. 316)
Serienschaltung von Bogenlampen im Filmatelier (p. 319)
Eugen Bauer GmbH feiert das fünfzigjährige Bestehen (p. 322)
Bauer B 8 B—ein neuer Kegelblenden-Kinoprojektor (p. 324)

Motion Picture Herald (Better Theatres Section) vol. 201, Oct. 1955

The Todd-AO Wide-Film System (p. 8) *G. Schutz*

Radio and Television News vol. 54, Oct. 1955

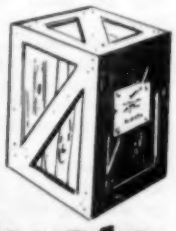
Industrial TV (p. 37) *W. H. Buchsbaum*
Width Troubles in TV Receivers (p. 56) *S. Heller*
Projection Color TV with a Color Wheel (p. 64) *J. Stanley*

Studio Review (Supplement to Kinematograph Weekly) Sept. 29, 1955

A New Debrie Camera for CinemaScope Filming (p. ix) *R. H. Cricks*

Television Magazine vol. 12, Aug. 1955

Definition of Coverage (p. 28)



new products

(and developments)

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products or services.

To measure lenses objectively, an electronic instrument has been developed by the Radio Corp. of America, according to an announcement by M. C. Batsel, Chief Engineer of RCA Engineering Products Div., Camden, N.J. The lens-tester is described as a major advance in the optical sciences, in that it will introduce accuracy, speed and economy in pre-rating lenses of all types. It will enable the selection of lenses by specific grade, with the exact characteristics for given applications. The electronic lens-tester resulted from initial research conducted by Otto H. Schade, who has pioneered in the development of universal ratings and allied test equipment — see, for instance, Dr. Schade's article in this issue.

Heretofore, the quality of any lens, with regard to sharpness, contrast and gradation, has been determined solely by visual tests. The lens-tester has been designed to enable lens manufacturers and users to determine quickly the lens' response characteristics and apply them against mathematical optimums. Many significant properties of an image depend upon the characteristics of its star image — the image of a point source of light. The star image of an optical "circuit" has been demonstrated to be the counterpart of the impulse response of an electrical circuit. Accordingly, the mathematical relationship of electrical impulse response, frequency responses and edge transitions can be applied to compute counterpart properties of optical star images.

Major components of the developmental RCA lens-tester include a special test drum, a microscope, a multiplier phototube and an oscilloscope. The test drum has nine groups of high contrast black and white lines of different widths, ranging from 3/in. for the course group to 200/in. for the finest group. The black lines correspond to 3 to 200 TV lines/mm in the image.

To obtain the square-wave flux response of a given lens, it is made to view the test drum, which is revolved by a synchronous motor. The lens is also rotated, about its transverse axis, to test its performance off axis. The lens image of the test drum is then scanned by the multiplier phototube through a narrow slit. For a theoretically perfect lens, the contrast between black and white lines, as measured by the phototube, would be modified only by diffraction effects. With a practical lens, the contrast deteriorates as the line width decreases due to the combined effects of diffraction and aberrations, or defects. The line at which

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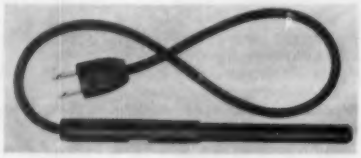
the contrast disappears represents zero square-wave flux response for the given lens.

In a typical test operation, such as many in which RCA is now using the experimental equipment, the lens is fixed 26.4 focal lengths from the test drum. The lens image is 25.4 times smaller than the object and is tested from 3 to 200 TV lines/mm. The microscope enlarges the lens image so that the phototube slit may be several thousandths of an inch wide. A cathode follower mounted at the base of the multiplier phototube is activated by the phototube's reaction and produces a low impedance output signal which is fed to the amplifier and power supply chassis. After amplification, the phototube's square-wave signal is rectified and its waveform presented on the oscilloscope. This waveform represents the average square-wave response vs. TV lines/mm for the lens and it can be used to determine mathematically the quality response or rating of the tested lens.



The Magnetic Erasing Pencil Type 8905 is an accessory developed by Cinema Engineering Co., Burbank, Calif. Designed for erasing small areas, even such as a syllable or part of a word, it is the size of a large fountain pen. It operates on 115-v a-c, 60 cycles at 10 w. The Cinema Engineering Co. has a companion product in its Degausser Type 9205, a tank-type bulk eraser for tape and film. It is for bench use, has a shipping weight of 27 lb, and operates on 115-v a-c, 60 cycles, 2,000 w.

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4. Stereophonic Reel	Picture with stereo sound and 12,000-cycle control signal on track four	330 ft.*	(ST-1)
5. Flutter Film	3000-cycle, 4-track	50 ft.	(FL-1)
6. Loudspeaker Phasing Film	Signal of uniform level, 400-cycle or 500-cycle frequency-warbled simultaneously on tracks 1, 2, and 3, at a 5-cycle rate (specify crossover frequency desired)	50 ft.	(LP-1)
7. Constant Level Film	8000-cycle, 4-track to check azimuth	50 ft.	(AZ-1)
8. Channel-Four Film	12,000/1000 cycle	50 ft.	(CH-4)
9. Projector Alignment Chart	Picture Only	100 ft.	(PR-1)
10. Projector Alignment Chart—Optical Track	Picture only, standard sprocket holes (made by Motion Picture Research Council)	100 ft.	CSOS

*These lengths approximate.

BASIC SET consists of types 1, 2, 7 and 9. This group is a "must" for every theater service engineer.

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The Du Mont Vitascan Color Studio Scanner is a system for producing live color television pictures of high quality without the use of expensive color television cameras. The Vitascan is a modern version of the early forms of live television pickup which used the flying-spot scanning principle. The basic flying-spot scanner equipment is similar to that already incorporated in the Du Mont Multiscanner for scanning color slides and color film, which uses a 7-in. high-voltage cathode-ray tube with a nonbrowning, neutral density faceplate, operating at 40 kv.

The major differences between the flying-spot scanner operation for the transmission of transparencies and that for live pickup are: (a) the scanning light is reflected from the objects or persons to be televised rather than transmitted through the material as in the case of a transparency; (b) the scanned area is many thousand times larger for live pickup than for slide or film operation and; (c) additional illumination must be provided in the studio.

Equipment additional to the Du Mont Multiscanner package for adapting it for live color pickup includes a complement of clusters of multiplier photo cells, 5 in. in diameter covered with suitable color filters, and means for strobe-lighting the studio during the vertical blanking interval of the television system. A mobile scanner complete with lens turret and electronic viewfinder, similar in appearance to standard television studio cameras, operates as a scanner light source independent of the multiscanner package. This Vitascan "camera" utilizes a 5-in. cathode-ray tube operating at 35 kv.

Lighting effects similar to those presently obtained in present studio television lighting

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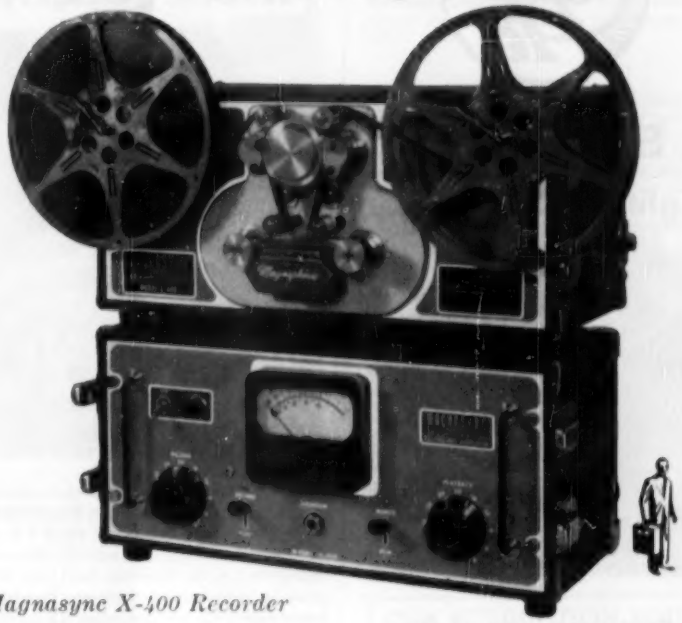

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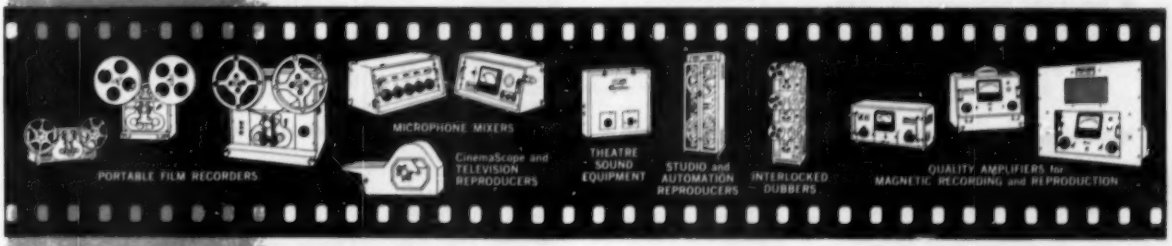

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SAN FRANCISCO—Brooks Camera Co., 45 Kearney St., San Francisco, Calif. EXbrook 2-7348.

CANADA—Alex L. Clark, Ltd., 3745 Bloor St., Toronto 18, Ontario. BElmont 1-3303.

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are achieved and controls are available for dissolves and fades from one "camera" to another. The Vitascan has no registration problems and is reported to afford excellent color reproduction because the transfer characteristic of the basic package is completely linear and devoid of matching problems.

Texture-Flex is a rubber-like material originally designed for use in Broadway and TV productions. Sheets are sized 4 ft × 8 ft. It is reported as made with life-like colors integrated in the material, but other colors may be achieved by painting. Besides the stone and brick textures, other backgrounds include weathered wood planking and shingles, tree bark, cut stone, tree stumps, hedges, leaves, rocks, sea shells and architectural elements such as scrolls, pilasters, balusters and fountain figures. A catalog is available from Texture Flex Div., Chester Rakeman Scenic Studios, Inc., 625 W. 43 St., New York 36.

Anscochrome, Ansco's new high-speed color film, is now available in 16mm daylight-type motion-picture film. It has an exposure index of 32 and is supplied in 50-ft magazines at $6.95 each and 100-ft rolls at $10.40 each. Anscochrome has been made to allow for better pictures in dimmer light and permit use of smaller lens openings for greater depth of field. The new high-speed film permits a greater number of subjects and types of action to be shot in slow motion at high frame speeds. Manufacturing innovations have been made in the film to reproduce red tones more accurately. Processing is included in the purchase price and may be done at the Ansco Color Laboratories listed in the film's instruction sheet.

Cronar, the polyester photographic film base developed by Du Pont, is expected to be in commercial production late this year or early in 1956. Du Pont has announced that a full-scale production plant is now in test operation at Parlin, N.J., after nearly two years of construction. This culminates eight years of research and development costing more than $6 million.

The Du Pont Company has announced that it has licensed Eastman Kodak Co. to manufacture polyester photographic base and film under Du Pont patents. Eastman has been reported as indicating it has as yet no plans for using the polyester base.

The Du Pont production plant is reported uniquely designed for photographic film manufacturing, being a five-story open-air structure for the chemical-mixing and formulation phases. Much of the plant can be monitored from a single instrument and control board. Graphic arts photographic emulsions will be the first made, with motion-picture products next in priority.

Journals Available and Wanted

These notices are published as a service to expedite disposal and acquisition of out-of-print Journals. Please write direct to the persons and addresses listed.

Available

Sept., 1937; March, 1939; June, 1939; July–Dec. 1941; 1942 through 1953; 1954 complete, with exception of Dec.; 1955 to date. Available only as entire lot. Write E. J. Mauthner, 310 Riverside Drive, New York 25.

Jan. 1930 through Dec. 1937, Journal SMPE issues; Jan. 1930 through Dec. 1935, bound volumes of SMPE Journal; SMPE Transactions: Apr. 1919: 8; May 1920: 10; May 1922: 13; Oct. 1922: 15; May 1925: 21; Oct. 1925: 24; Apr. 1927: 30; Sept. 1927: 32; Apr. 1928: 33; Sept. 1928: 36. SMPE Membership Listings: 1928, 1930, 1938; SMPE Index and Authors: 1930–1935; SMPE Miscellaneous: ASA Z22—1930; Dim. Stab of M.P. Films 1934; ASA Z22—1935; High Intensity Lamps—1935; Program Spring Convention Apr. 26, 1939. Write John Faber, 5 Edgewater Drive, Denville, N. J. Phone Rockaway 9-2623M.

June 1940 through Jan. 1950. Write Earle F. Orr, 345 Fellsway West, Medford, Mass.

Dec., 1936; Jan., Feb., Apr., May, July, Sept., Nov. 1937; 1938 complete; 1939 complete; 1940 complete; Jan.–Aug. 1941. Write Richard S. Norton, Warner News Inc., 625 Madison Ave., New York 22.

Collection of back issues available either singly or as a lot. Write F. H. Cole, 1258 So. Burnside Ave., Los Angeles 19.

Wanted

All Journals published in 1938 or earlier. Write John P. Byrne, Motion Picture Sensitometrics, Signal Corps Pictorial Center, 41-15 48 St., Long Island City 4, N.Y. Thanks are due Major R. E. Herold, Glendale, Calif., who furnished those for 1954, and M. G. Sinkewitch, Hollywood, who donated a complete set for the years 1939 through 1953.

May, July 1944; Jan., Apr. 1945; Jan., Feb. 1946; Jan., Feb., Apr. 1947; Feb. 1950. Write Kraus Periodicals, Inc., 16 East 46th Street, New York 17.

High-Speed Photography, Volumes 2 and 3. Write William T. Mills, University of North Carolina, Dept. of Agriculture & Engineering, Raleigh, N.C.

Complete set of Transactions. Write John Flory, Eastman Kodak Co., 343 State St., Rochester 4, N. Y.

High-Speed Photography, Volumes 1, 2 and 3. Write Jack Gershon, Armour Research Foundation, Technology Center, Chicago 16.

Transactions Nos. 6 and 9. Write W. W. Hennessy, 503 West 41 St., New York.

Transactions Nos. 1, 5, 6, 7 and 9. Write Lloyd E. Varden, Pavelle Color Inc., 533 West 57 St., New York 19.

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These notices are published for the service of the membership and the field. They are inserted three months, at no charge to the member. The Society's address cannot be used for replies.

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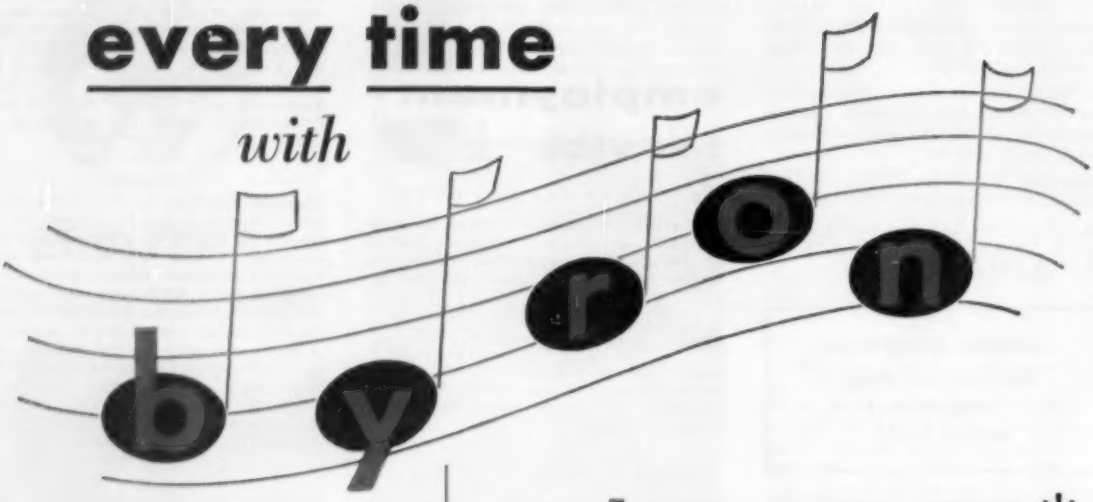

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Meeting Calendar

American Physical Society, Nov. 25–26, University of Chicago, Chicago, Ill.

American Institute of Chemical Engineers, Nov. 27–30, Hotel Statler, Detroit.

American Chemical Society, Southwest Regional Meeting, Dec. 1–3, Shamrock Hotel, Houston, Texas.

International Atomic Exposition, Dec. 10–16, American Institute of Physics, Public Auditorium, Cleveland, Ohio.

Acoustical Society of America, Dec. 15–17, Brown U., Providence, R.I.

Mathematical Association of America, Dec. 30, Rice Institute, Houston, Texas.

American Association for the Advancement of Science, Annual Meeting, Dec. 26–31, Atlanta, Ga.

National Symposium on Reliability and Quality Control, sponsored by I.R.E., American Society for Quality Control, and Radio, Electronics, and Television Manufacturers Association, Jan. 9–10, 1956, Hotel Statler, Washington, D. C.

SMPTE Central Section, Jan. 16, 1956; Feb. 20, Mar. 19, Apr. 16, May 21, June 18.

Association of Cinema Laboratories, Jan. 26, 1956, New York.

International Symposium on Nonlinear Circuit Analyses, II; sixth of a series sponsored by the Polytechnic Institute of Brooklyn, Apr. 25–27, 1956, Engineering Societies Building, New York.

American Institute of Electrical Engineers, Winter General Meeting, Jan. 30–Feb. 3, 1956, Hotel Statler, New York.

American Institute of Physics, 25th Anniversary Celebration, Jan. 30–Feb. 4, 1956, Hotel New Yorker, New York.

Optical Society of America, Feb. 1, 1956, (Massachusetts Institute of Technology, Cambridge, Mass.).

Acoustical Society of America, Feb. 1, 1956, (57 E. 55 St., New York 22).

Optical Society of America, Apr. 5–7, 1956, Bellevue-Stratford, Philadelphia, Pa.

79th Semiannual Convention of the SMPTE, including Equipment Exhibit, Apr. 29–May 4, 1956, Hotel Statler, New York.

80th Semiannual Convention of the SMPTE, Oct. 7–12, 1956, Ambassador Hotel, Los Angeles.

Optical Society of America, Oct. 18–20, 1956, Lake Placid Club, Essex Co., N.Y.

Optical Society of America, Mar. 7–9, 1957, Hotel Statler, New York.

81st Semiannual Convention of the SMPTE, Apr. 28–May 3, 1957, Shoreham Hotel, Washington, D.C.

82nd Semiannual Convention of the SMPTE, including Equipment Exhibit, Oct. 6–11, 1957, Hotel Statler, New York.

83rd Semiannual Convention of the SMPTE, April 20–26, 1958, Ambassador Hotel, Los Angeles.

84th Semiannual Convention of the SMPTE, Oct. 19–24, 1958, Sheraton-Cadillac, Detroit.

85th Semiannual Convention of the SMPTE, May 3–8, 1959, Fontainebleau, Miami Beach, Fla.

86th Semiannual Convention of the SMPTE, including Equipment Exhibit, Oct. 5–10, 1959, Hotel Statler, New York.

SMPTE Officers and Committees: The rosters of the Officers of the Society, its Sections, Subsections and Chapters, and of the Committee Chairmen and Members were published in the April Journal.

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